ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY
COLLEGE OF ARCHITECTURE AND CIVIL ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

Master thesis on:

# Hydraulic Analysis of Road Drainage Structures and Proposed Mitigation Measures (Case study of Bule hora to Yirgacheffe Asphalt Road).

By Mitiku Chachu

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Thesis submitted to school of graduate studies, Addis Ababa Science and Technology University, for the in partial fulfillment of the requirement for the Degree of Masters of Science in Civil engineering

(Hydraulic Engineering Major)

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# APPROVAL PAGE

This MSc thesis entitled with **"Hydraulic Analysis of Road Drainage Structures and Proposed Mitigation Measures (case study BuleHorato Yirgacheffe Asphalt Road)."** has been approved by the following examiners in partial fulfillment of the requirement for the degree of Master of Science in Hydraulic Engineering.

**Date of Defense: June 9, 2018**

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## CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa Science and Technology University a dissertation entitled "**Hydraulic Analysis of Road Drainage Structures and Proposed Mitigation Measures ( Case Study of BuleHorato Yirgacheffe Asphalt Road).**" in partial fulfillment of the requirement for the degree of Master of Civil Engineering in Hydraulic Engineering major.

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## DECLARATION AND COPY RIGHT

Mitiku Chachu, declare that this thesis is my own original work that has not been presented and will not be presented by me to any other University for similar or any other degree award.

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Most sincerely, I wish to thank the Almighty God for being my guide, hope and strength.

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**ABSTRACT:**

This thesis presents results of the hydraulic analysis of drainage structures; on Yirgachefe to Hageremariam road and proposed mitigation measures using hydraulic and hydrologic analysis software like GIS, Watershed Modeling System (WMS), HEC-RAS and Global mapper. Drainage is a must component in the road construction. In lay world language we know that tarmac and water are never "best friends." To mitigate premature pavement failures and to enhance the road performance, it is imperative to provide adequate drainage structures. The necessary data for this research are Digital elevation model, surveying data, rainfall data, and progressive report of construction and feasibility study of the road. The primary and secondary data sources were used. Hydrological analysis was carried out by using rational method for area less than 50hectar and SCS method for area greater than 50hectar. IDF curves were developed using historical rainfall time series data. The research pointed out areas of concern for hydraulic analysis drainage of road great importance during road construction to ensure that, the constructed road is put to use without failure before the actual design life. From analysis, result shows us culvert was overtopped by excess flow. Calculated peak discharge and open size of pipe culvert are inadequate also scouring problem is series in area. The review concluded that effect of poor drainage condition on a road is very adverse. From study it can be concluded that road surface drainage of the *Hageremariam* to *Yirgachefe* found to be inadequate due to insufficient drainage structures provision.

Key Words: culvert, Drainage, Road, structures, analysis, IDF curve

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ACRONYMS AND ABBREVIATION

ADO: Arizona Department of Transportation

BVI: British Virgin Islands

SCS: Soil Conservation Services

CN: Curve Number

CSA: National Census Agency

DDM: Drainage Disign Manual

DEM: Digital Elevation Model

DS: Design Standard

EIA: Environmental Impact Assessment

EMA: Ethiopian Mapping Agency

ERA Ethiopia Road Autority

FAO**:** Food and agricultural organization

GPS: Global Postion Sysitem

GRD: Guide to Road Design

HEC-RAS: Hydrologic Engineering Center River Analysis Sysitem

HVS: Heavy Vehicle Simulator

IDF: Intesity duration Frequence curve

PASDEP: Plan for Accelerating Sustanable Development to End Poverity

RAP: Resettlement Action Plan

SCS: Soil Conservation Sysitem

SNNPR: Southern Nations, Nationalities and People's Region

TR: Technical Reliase

USA: United States of America

UTM: Universal Transform Merkator

WATMOVE: Water Movements in Road Pavements and Earthworks

WMS: Watershed Management System

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## CHAPTR ONE

## INTRODUCTION

### 1.1 Back ground.

Water is the most important compound ensuring life in this planet. But on roads the presence of water means mainly trouble. A main cause of road damage, and problems with the serviceability of road networks, is excess water filling the pores of road materials in the road and in the subgrade soils. It is generally known that road structures operate well in dry conditions and because of this roads historically have been built on dry terrain. On those occasions where roads have had to be built on wet terrain, drainage structures have usually been designed to keep the road structures dry. The first roads in Europe were built about 3500 years ago. Already at that time engineers designed the road structures to take into account the importance of drainage. They paid attention to cross-fall (to help water to flow to the lateral ditches), grade line (the road surface should be above of the groundwater table and the surrounding ground) and lateral ditches (to convey water away from the road structure and prevent water table rise) (Dawson, 2002).

Drainage is a must component in the road construction. In lay world language we know that tarmac and water are never “best friends.” For this reason in most designs of the road, the first thing to be put in place is drainage system. The presence of water in the pavement layer will tend to reduce the bearing capacity of the road and thereby its lifetime. It is required that the surface water from carriage ways and the shoulders should be efficiently drained off without allowing it to the subgrade of the road (Victory K. Rono, 2014).

Drainage system is a process of removing and controlling excess surface water with in right of way. Drainage is an important feature in determining the ability of given pavement to withstand the effects of traffic and environment. (Adequate drainage is very essential in the design of highways since it affects the highway’s serviceability and usable life. If ponding on the traveled way occurs, hydroplaning becomes an important safety concern. Drainage design involves providing facilities that collect, transport and removes storm water from the highway (O‟Flaherty, et al., 2000).

The objective of drainage system is to prevent onsite water standing on the surface and convey the offsite storm runoff from one side of the roadway to the other. To carry out the offsite drainage. Culverts are closed conduits in which the top of the structure is covered by embankment (ERA Drainage Design Manual, 2013).

As the water can cause a serious impact on both the road access and its strength, an efficient drainage system is the most important part of road construction and maintenance works.

Good drainage needs to be taken into consideration at the early design stages in order to secure a long life for the road. With a well-designed drainage system, future rehabilitation and maintenance works can be considerably reduced and thus limit the costs of keeping the road in a good condition.

Ensuring good drainage begins when selecting the road alignment. A Centre line that avoids poorly drained areas, large runoffs and unnecessary stream crossings will greatly reduce the drainage problems. Provision of sufficient drainage is an important factor in the location and geometric design of highways. Drainage facilities on any highway or street should adequately provide for the flow of water away from the surface of the pavement to properly designed channels. In addition, traffic may be slowed by accumulated water on the pavement, and accidents may occur as a result of hydroplaning and loss of visibility from squish and sprig. The importance of enough drainage is recognized in the amount of highway construction dollars allocated to drainage facilities. About 25 percent of highway construction dollars are spent for erosion control and drainage structures, such as culverts, bridges, channels, and ditches (Wyatt, 2000).

Surface drainage encompasses all means by which surface water is removed from the pavement and right of way of the highway or street. A properly designed highway surface drainage system should effectively intercept all surface and watershed runoff and direct this water into adequately designed channels and gutters for eventual discharge into the natural waterways. Water seeping through cracks in the highway riding surface and shoulder areas into underlying layers of the pavement may result in serious damage to the highway pavement. The major source of water for this type of intrusion is surface runoff. An adequately designed surface drainage system will therefore minimize this type of damage. The surface drainage system for rural highways should include sufficient transverse and longitudinal slopes on both the pavement and shoulder to ensure positive runoff and longitudinal channels (ditches), culverts to provide for the discharge of the surface water to the natural waterways. Storm drains and inlets are also provided on the median of divided highways in rural areas. In urban areas, the surface drainage system also includes enough longitudinal and transverse slopes, but the longitudinal drains are usually underground pipe drains designed to carry both surface runoff and ground water. Curbs and gutters also may be used in urban and rural areas to control street runoff, although they are more frequently used in urban areas (Wyatt, 2000).

The ancient Romans who started building the 50,000 mile Imperial Roman road network in 312 B.C knew of the damaging effects of water and tried to keep their roads above the level of the surroundings terrain. In addition to constructing these roads with thick section, they often provided a sand layer on top of the sub-grade. The durability of those highways is provided by the fact that many of them still exist (Muhammad, 2014).

Drainage facilities are required to protect the road against damage from surface and sub-surface water. Traffic safety is also important as poor drainage can result in dangerous conditions like hydroplaning. Poor drainage can also compromise the structural integrity and life of a pavement. Drainage systems combine various natural and a man-made facility e.g. ditches, pipes, culverts, curbs to convey this water safely (US Forest Service, 1979).

*Yirgachefe – Hageremariam* Road Project is part of Mombasa-Nairobi-Addis Ababa Corridor Project aims at promoting trade and regional integration between Ethiopia and Kenya by improving transport communications between the two countries. The expected outcomes of the project include reduced transport and shipping costs between Kenya and Ethiopia; reduced transit time for import and export goods; and increased volume of Ethiopian transit goods using the port of Mombasa. The development of the corridor will expand market sizes beyond national boundaries and foster a conducive and enabling environment for the private sector and for attracting foreign direct investments. In addition to enhancing trade and strengthening regional integration, the project will contribute to poverty reduction in both countries by increasing access to markets and social services for the surrounding areas, and communities, and by empowering women and other disadvantaged groups through adequate roadside socio-economic infrastructure and services (Arab contructor report, 2017).

Ethiopia's second Poverty Reduction Strategy (2005-2010), known as the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) accords high priority to infrastructure development to support industrialization and development and commercialization of agriculture. Accordingly, within the context of the PASDEP, Strengthening the Infrastructure backbone of the Country, Ethiopia's five-year Road Sector Development Strategy III is putting emphasis on expanding the road network and improving regional trade corridors and port linkages. Rehabilitation of *Yirgachefe – Hageremariam* road is a continuation of Government efforts to improve the standard of Trans – East African Highway as a member of common market for east and southern Africa (COMESA) countries and its import-export corridors to minimize the cost of its transit traffic (Arab contructor report, 2017).

*Yirgachefe – Hageremariam* road is located in the Southern Nation and Nationalities and People (SNNP) Regional State. The project alignment starts at *Yirgachefe* and ends at *hageremariam*. The existing project road was built several years ago with asphalt concrete and currently serves moderate level of traffic. The traffic volume on the road is expected to increase in near future when the country commence to use Kenya's port of Mombasa and Isilo – *Moyale* road to bitumen road which provides short cut to the port.

Accordingly, a contract was signed on May 14, 2004 between Ethiopian Road Authority of Ethiopia (ERA) and Arab contractor Pvt. Ltd. Ethiopia to carry out the Consultancy Services for the Feasibility Study, Environmental Impact Assessment (EIA), Preparation of Resettlement Action Plan (RAP), Detailed Engineering Design and Tender Document Preparation for *Yirgachefe – Hageremariam* Road Rehabilitation Project (Arab contructor report, 2017).

### 1.2 Statement of the problem

Successful drainage depends on early detection of problems before conditions require major action. Signs of drainage problems requiring attention include: puddles on the surface area, poor surface flow, slope erosion, clogged ditches, pavement edge raveling, preliminary cracking, pavement pumping, and surface settlement (L.M. Nyuyo, 1993).

On *Hagermariam-Yirgachefe* road, drainage structures are not properly functioning at different station. The main causes are the inadequacy of drainage structures during the rainy season to pass the flood, poor quality construction, inappropriate site selection and improper alignment of some drainage structures with respect to the road alignment. These shortcomings cause damage to superstructures of drainage structures and stream crosscurrents are significant factors. Improper skew i.e. improper alignment of drainage structures with respect to the natural channel and the roadway can greatly aggravate the magnitude of scour.

Deforestation of land occurred on both sides of the road due to the agricultural activities of farmers and indigenous people. This has resulted in accelerated soil erosion and its accumulation in the drainage structures. This causes storm water to overflow on the carriageway and clogging of culverts by silts. In addition to silts, the logs and tree branches are transported to the drainage structures on the upstream side of the culverts. These are the main causes for the clogging of these drainage structures, which causes overtopping of embankment by flood.

As a result, spending of a large number of dwellers shift their house during the rainy season and the municipality spend large amount of money to removal of the logs, branches of trees and the silt accumulated in the drainage structures.

Runoff, which is in excess of the drainage structures capacity, overtops the road embankment and makes the road to function improperly due to erosion and ponding.

The wearing-course and sub-grade of the road become weak due to high moisture content and the road could not carry traffic as the intended design requirement.

Moreover, at some stations even if construction of bridge is required, culverts with inadequate rows of pipe were constructed. This created the road to be malfunction during the rainy season every year due to overtopping. To alleviate this problem, culvert and bridge drainage structures performance will be evaluated and mitigation measures shall be propose for sustainable and proper functioning based on ERA drainage design manuals.

## 1.3 Objectives of the Research

### 1.3.1 General objective

The general objective of the study is to evaluate the performances of the existing road drainage structures and to propose mitigation measures that minimize frequent maintenance of drainage structures and roadways on *Hagermariam-Yirgachefe* road.

### 1.3.2 Specific objectives

- To assess the conditions of the existing drainage infrastructure inlets, lines, outlets and watersheds.
- To identify the major challenges in drainage system.
- To evaluate the hydraulic capacity of the different drainage elements.
- To examine the impacts of drainage underperformance on road performance.

## 1.4 Research questions

The fundamental questions that are addressed and investigated are:

- What are the major causes of drainage structures faller on *Hagermariam-Yirgachefe road?*
- What are the types of drainage structures failures on *Hagermariam-Yirgachefe* road?
- Are the hydraulic capacities of the different drainage elements of the road adequate?
- What is the impact of drainage underperformance on road?

## 1.5 Significance of the study

This study, generally, contributes the following major significances:

Therefore, this study is beneficial to the region for future road drainage structures construction to avoid problems by assessing the performances of the existing drainage structures and proposing mitigation measures to avoid improper functioning.

The study may beneficial for researchers who conduct similar researches on other road drainage structures, soil conservation strategies, erosion and scouring prevention mechanisms and aggradations or degradations of the stream channel.

Policy makers and any organization working in the area of roads and urban storm water drainage infrastructure may can use it as a reference to fill the existing gap between road and drainage design and construction.

## 1.6 Scope of study

This study is geographically limited to Hageremariam to yirgachefe road of Ethiopia. Generally, it was addressed issues related to drainage structures and its integration with road provision.
Even though drainage problem exist all over the country it is difficult to have a look at each road of whole country. Therefore Hagermariam-Yirgachefe roads are taken and analysis was done on different drainage structures like culvert, bridge, road side ditch and curbs to convey water safely.

The thesis is limited to the hydraulic analysis of Hagermariam-Yirgachefe road drainage system of asphalt pavement and proposing mitigation measures of the problem that are finding only on drainage system.
It would look at the various steps that should be taken so as to ensure sufficient drainage system and how water causes increase in moisture content which eventually decreases the strength of the road and subsequently, road deterioration.

## 1.7 Limitation of study

The information from the field study in *Yirgachefe* to *Hageremariam* road is mostly based on information from written reports and site observation of existed drainage structures related to the project and interviews with key persons from governmental agencies and from the Arab road construction project organization. Consequently, important information may have been overlooked.

During the interviews it has often been difficult to obtain the desirable answers of questions, because of misunderstandings. Even though the matter was put forward in different ways, much information has most likely been lost in translation. Also the general culture in Ethiopia that implies that persons from both governmental bodies and private institutions are restrictive with sharing information, have made it difficult to judge the quality of the obtained information.

## 1.8 Organization of the thesis

The first chapter of this study which is the introduction of the research contained; -background of the study road, problem statement, both general and specific objective of the study, research question, significance of the study, scope and limitation of the study.

The second chapter contained the review of literature and the third chapter which is design and methodology of the research which incorporates:-data collection, methods and tools, procedures and study area. The fourth chapter was focused on analyzing of the data collected during the survey and the findings including discussion of the finding.

The last chapter which is the fifth deal with the conclusion and recommendations of the study based on the result of the research and the general review of the literature. Finally, bibliography, appendices, references and other necessary write ups are annexed at the end of the paper.

# CHAPTER - TWO

# LITERATURE REVIEW

## 2.1 General Description of Road Drainage Structures

Road drainage structures that cross the rivers and valleys are vital components of the road network that contributes greatly to the national development and public daily life.

Any damage or collapse of these structures can cause the risk of the lives of road users as well as create serious influence to the entire country economic development.

Furthermore, the reconstruction of these road drainage structures needs considerable amount of skilled work force, money and time. Road drainage structures are essential components during the design development of road infrastructures. Drainage structures intended to allow the runoff of any flow of water with limited damages and disturbances to the road and to the surrounding areas.

The two main types of water flows that can be considered are the flows that usually crossing the area that could be diverted by the presence of the road, and the flows generated by the runoff of the rainwater falling on the carriageway and its surroundings. The basic design techniques in roadway drainage system should be developed for economic design of surface drainage structures including ditches, culverts and bridges (ERA, 2013).

## 2.2 Road Crossing drainage structures

A hydraulic investigation and analysis of both the upstream and downstream reaches of the watercourse is necessary to determine the best location, size, and elevation of the proposed crossroad structure, whether a culvert or a bridge. The investigation should ensure that any roadway structure or roadway embankment that encroaches on or crosses the flood plain of a watercourse will not cause significant adverse effect to the flood plain and will be capable of withstanding the flood flow with minimal damage. It is significant to provide attention during design of the magnitude, frequency and appropriate water surface elevations for the design flood, the 100-year flood, and the overtopping or 500-year flood for all structures (ADOT, 2007) .

The impact of sediment and other floating materials can attribute the damage of bridge deck (Melville and Coleman, 2000). A freeboard of 1.5m should be provided for bridges, for smaller streams of expected less size of debris, a freeboard of less than 1.5m is provided however, according to ERA draft drainage design manual, the minimum freeboard must not be less than 1.0m (ERA, 2011). Culverts can be classified into two based on their functional types, stream crossing and runoff management.

Stream crossing culvert is a drainage structure installed on the stream with recommended skewed angle, $15^0$- $45^0$ if conditions do not permit to install normal to the stream channel. Installing culverts normal to the stream channel decreases construction cost. Where large skew angles are required, consideration of the most appropriate road alignment is significant (Austroads , 1994).

Runoff management culvert strategically placed to manage and route roadway runoff along, under, and away from the roadway. Many times these culverts are used to transport upland runoff, accumulated in road ditches on the upland side of the roadway, to the lower side for disposal. Highway drainage is the process of removing and controlling excess surface and sub-surface water within the right way. This includes interception and diversion of water from the road surface and subgrade. The installation of suitable surface and sub-surface drainage system is an essential part of highway design and construction. Highway drainage is used to clear surface water from the highway (Austroads , 1994).

Good highway drainage is important for road safety. Roads need to be well drained to stop flooding; even surface water can cause problems with ice in the winter. Water left standing on roads can also cause maintenance problems, as it can soften the ground under a road making the road surface break up and as well lead to an accident from the road users (Amit, 2016).

(Muhammad, 2014) studied highway drainage system and started that highway is importance for removing water from the road surface, preventing ingress of water into the pavement, passing water across the road, either under or over and preventing scour and/ or washout of the pavement, shoulder, batter slopes, water courses and drainage structures. He identified types of drainage on the highway to include kerb and gullies, surface water channel, combined filter drain (French drain), over-the-edge drainage, drainage channel locks, combined kerb and drainage units, linear drainage channels, fin and narrow filter drain (sub-surface drainage) and edge drainage for porous asphalt.

According to civil engineering dictionary (Engineering Dictionry, 2004), highway drainage includes collecting, transporting, and disposing of surface/subsurface water originating on or near the highway right of way or flowing in streams crossing bordering that right of way. This is important because of water damage highway structure in many ways. The water which are dangerous for highways are: Rainwater: Cause erosion on surface or may seep downward and damage pavement (surface drains), Groundwater: May rise by capillary action and damage pavement (sub-surface damage) and water body: May cross a road (river/stream) and may damage road (cross drainage words).

In a research on drainage on roads by (Singh et al., 2014), a well-designed and well maintained road drainage is important in order to minimize the environmental impact of road runoff on the receiving water environment, ensure the speedy removal of surface water to enhance safety and minimize disruption to road users and to maximize the longevity of the road surface and associated infrastructures. Water in the pavement system can lead to moisture damage, modulus reduction and loss of strength. In order to prevent such damages to the pavement, it is essential to provide proper drainage to the roads. They maintained that the presence of water in a highway layer reduces the bearing capacity of the road, and in doing so it also reduces the structure's lifetime. Highway drainage is used to clear surface water from the highway. Roads need to be well drained to stop flooding; even surface water can cause problems with ice in the winter. Water left standing on roads can also cause maintenance problems, as it can soften the ground under a road making the road surface break up (Singh et al., 2014).

### 2.2.1 Maintenance and design related drainage problems

The “maintenance related” category covers all of those drainage problems that can be avoided by good maintenance policies and practices.

Poor drainage maintenance can have a major effect on the lifetime of a pavement and annual paving costs. It can also affect traffic safety. For this reason accurate definitions and requirements for each drainage maintenance task should be included in the contract documents, and followed up on site to ensure that the contractor fulfills its duties (Berntsen and Saarenketo, 2006).

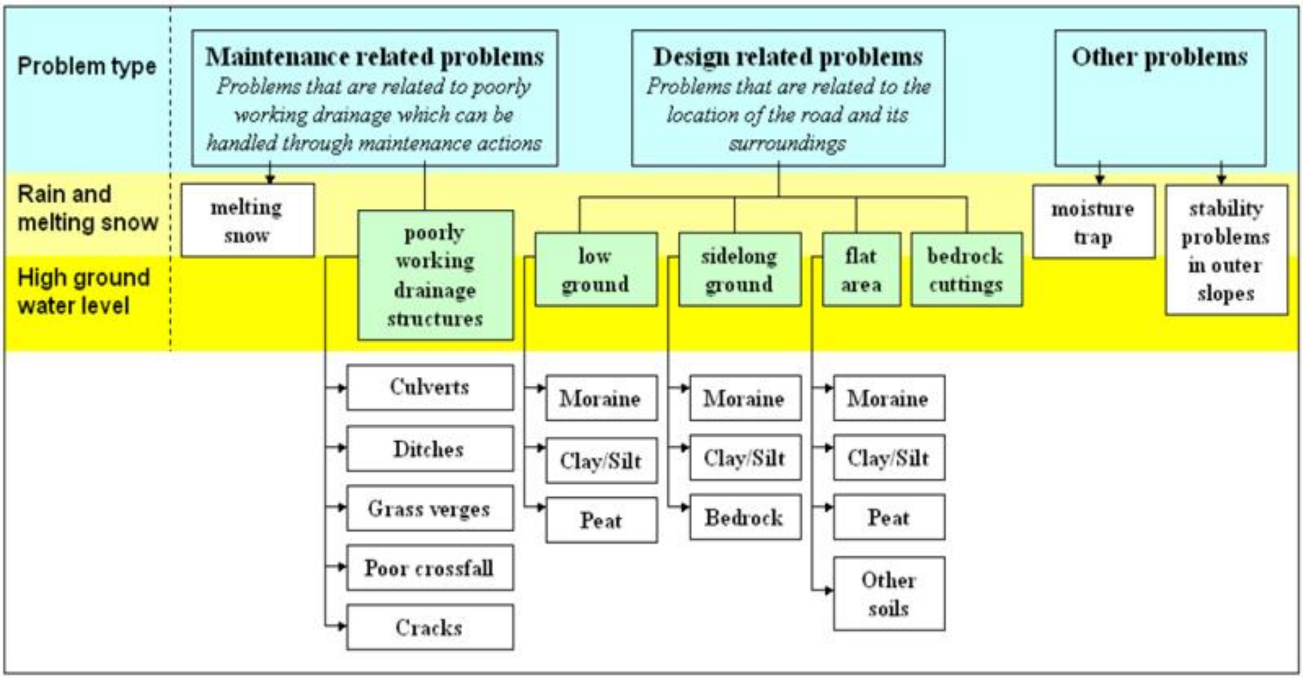


Figure 1 Road classification of drainage problems on low traffic volume roads according to Berntsen and Saarenketo.

### 2.2.2 Keeping Water Out Of Pavement

The best approach to prevent premature pavement failure from poor drainage is to keep water from entering the pavement system (Berntsen and Saarenketo, 2006).

Most water enter the pavement through joints, cracks and pores in the pavement. As noted earlier, effective means for minimizing surface infiltration is to provide adequate cross and longitudinal slopes, limiting/preventing ponding on the pavement and on the shoulders and keeping ditches, curb and gutter and other drainage conveyance systems unobstructed (Berntsen and Saarenketo, 2006).

Though it is impractical to keep all water off the pavement, it should be moved off the pavement and shoulders as quickly as possible into roadside ditches or inlets (Beaconl, 2015).

Moreover, roads can be relatively stable at a given moisture/water content but a change in moisture content, i.e., from heavy rain, can cause road to become unstable if materials become saturated. Road material can get saturated and unstable by excess water getting into the pavement through surface and subsurface flows (Beaconl, 2015).

As such, water entry into the pavement can be restricted by timely, periodic preventative maintenance surface treatments, i.e., crack sealing, seal coating and overlaying. And sub surface flow through effective engineering and construction.

Nonetheless, drainage control in the British Virgin Islands (BVI) will be challenging, for most roads will be in hilly terrain and align with steep slopes (gradient) that results in rapid runoff rates that cause excessive erosion of road surfaces and drains (Beaconl, 2015).

As such, side drains must /should be constructed to capture runoff from the pavement , along with intercepting runoff from the hill side or cut slope and convey directly into the sea.

Assuming proper design and construction of both the surface and subsurface drainage system, proper and timely maintenance– preventative, routine and emergency–is critical to preventing premature failure.

Proper drainage prevents the buildup of water in the pavement, reducing the damaging effects of traffic loading and the environment. Poor drainage, on the other hand, adversely impacts roads level of service (Beaconl, 2015).

## 2.3 Backwater Effect on Road Drainage Structures

When a roadway crosses a natural drainage way, the resistance to flow of the structure may increase the water depth upstream of the drainage structure. This backwater effect may cause areas close to the drainage way to become flooded where previously they remained above the floodwaters.

When dwellings or other manmade structures are close to the drainage way, a limitation placed on the maximum backwater effect tolerated for drainage structure design (DDM, 2003).

Aggradations increase the backwater effect; affect the pressure on the structure, and passes ability of the bridge (Johnson et al., 2002). Bridges seem to more readily allow sediment transport than culverts and therefore have less accumulation up stream of the crossing (Wellman et al., 2000).

## 2.4 Flow Velocity in Road Drainage Structures

The introduction of a culvert to convey the stream flow beneath a roadway can cause an increase in flow velocity downstream of the structure. The increased flow velocity may be sufficient to cause erosion and degradation of the channel profile. This effect can be detrimental to downstream land users and to the culvert itself. If the natural stream velocity exceeds the erosive velocity, then the increased velocity at the culvert outfall will accelerate this naturally occurring process. Erosive velocity must be avoided to protect lower lands and the roadway embankment. The flow velocity at the outlet of the roadway drainage works shall not exceed the erosive velocity of the channel or the natural velocity of the channel, whichever is greater (Wyatt, 2000).

Table 1Target Outlet Velocities

| Material Downstream of Culvert Outlet | Target Outlet Velocity (m/s.) |
|---|---|
| **Rock** | **4.5** |
| **Stone 150mm. diameter or large** | **3.5** |
| **Gravel 100mm. or grass cover** | **2.5** |
| **Firm loam or stiff clay** | **1.2-2.0** |
| **Sandy or silty clay** | **1.0-1.5** |

Source: derived from Austroads GRD part 5(2008)

## 2.5 Bridge

### 2.5.1 Bridge Scour

Scour is the erosion or removal of streambed or bank material from bridge foundations due to flowing water (Kattell, J. and Eriksson, M., 1998). It is the most common cause of roadway bridge failures. Every bridge over water assessed as to its vulnerability to scour in order to determine the prudent measures for that bridge and the entire inventory (Richardson and Davis, 1995). Scour can have a long-term impact on bed degradation and affect entire channel reaches (Simon, A.et al., 1999).

### 2.5.2 Bridge Sizing

**Design-Storm Frequency**. Should be used to determine the appropriate storm event for design. It shows the design-storm requirements for allowable backwater, outlet velocity, and road-serviceability freeboard (Indiana Department Of Transportation, 2012).

**Allowable Backwater**. This is the difference caused by a bridge between the upstream water-surface elevation and the natural condition with no bridge at the same location. The backwater is the maximum proposed bridge value that occurs at a given cross-section location.

**Road-Serviceability Freeboard.** The headwater elevation from the bridge should maintain a road-serviceability freeboard to the edge of pavement based on the facility level. If the facility level allows, embankment overtopping may be incorporated into the design, but should be located away from the bridge abutments and superstructure. The required road serviceability should be maintained throughout the entire flood reach of the stream. A larger downstream waterway should be checked to determine if its floodwaters can backwater through the system and affect road serviceability (Indiana Department Of Transportation, 2012).

**Structure Freeboard.** Where practical, a minimum clearance of 1m should be provided between the Q100 elevation and the low chord of the bridge to allow for passage of ice and debris. Where this is not practical, the clearance should be established based on the type of stream and level of protection desired as approved by the Office of Hydraulics (Mississippi Hydraulic department, 2012).

**Span Lengths**. Where possible, a single-span bridge is desired in lieu of a multi-span bridge, though this may sacrifice desired structure freeboard. The minimum span length for a bridge with more than three spans should be 100 ft for those spans over the main channel. A three-span bridge should have the center span length maximized at a site where debris can be a problem. For a two-span bridge, span lengths are subject to approval of the Office of Hydraulics (Indiana Department Of Transportation, 2012).

### 2.5.3 Scour-Hydraulic Modeling Using HEC-RAS

The hydraulic design model should be obtained. A velocity distribution at the bridge should be computed that will determine the maximum velocity that occurs (Mississippi Hydraulic department, 2012).

**Contraction-Scour Analysis.** Use live-bed calculations. Clear-water calculations should be used for scour just downstream of a dam, overflow structure on a floodplain, or other location where sediment in the stream is minimal.

**Pier Local-Scour Analysis.** Choose the Maximum V1Y1 method for determining pier scour. The channel can meander and the highest velocity can occur at the face of the pier.

**Total Scour Analysis**. Add the contraction scour and the pier scour for total scour depth. This should be subtracted from the flow line at the bridge to determine low-scour elevation. If analyzing an existing bridge, the foundation of the bridge should be checked against the low-scour elevation to determine if the bridge is scour critical. If an existing bridge foundation is unknown, the bridge is automatically considered scour critical (Indiana Department Of Transportation, 2012)

## 2.6 Surface drainage systems (ditches)

A surface drainage system collects and diverts storm water from the road surface and surrounding areas to avoid flooding. It also prevents damage to sub-surface drains, water supplies (wells) and other sensitive areas adjacent to roads. It decreases the possibility of water infiltration into the road and retains the road bearing capability (Faísca et al., 2009). Appropriate design of the surface drainage system is an essential part of commercial road design (O'Flaherty, C.A., 2002).

There are different types of trenches with different functions, but the majority of ditches are normally provided with V-shaped cross-sections. Depending on the location of the ditch relative to the road construction, it is called a cutting ditch, shallow ditch or covered ditch (Linde et al.,2010).

When rain falls on a sloped pavement surface, it forms a thin film of water that increases in thickness as it flows to the edge of the pavement. Factors which influence the depth of water on the pavement are the length of flow path, surface texture, surface slope, and rainfall intensity. As the depth of water on the pavement increases, the potential for vehicular hydroplaning increases (ERA, 2013).

### 2.6.1 Subsurface drainage systems (culverts)

Subsurface drainage systems drain water that has infiltrated through the pavement and the inner slope but also groundwater.

Subsurface drainage systems are directly linked to surface drainage systems (Faísca et al, 2009).

According to the SRA handbook, culverts are road constructions with a theoretical span of ≤2.0 m. Culverts have an open inlet and outlet and conduct water underneath a road. Particular care in both design and maintenance is required to prevent obstruction of water flow by obstacles (Vägverket, 2008).

Diversion of water from the central reservation of major roads is achieved with a pipe running either along or across the road to the subsurface drains on the excavation slope (ATB Väg , 2004) .

### 2.6.2 Storm water Collection

Storm water collection is a function of the minor storm drainage system which is accommodated through the use of roadside and median ditches, gutters, and drainage inlets.

**Roadside and Median Ditches** are used to intercept runoff and carry it to an adequate storm drain. These ditches should have adequate capacity for the design runoff and should be located and shaped in a manner that does not present a traffic hazard. If necessary, channel linings should be provided to control erosion in ditches. Where design velocities will permit, vegetative linings should be used.

**Gutters** are used to intercept pavement runoff and carry it along the roadway shoulder to an adequate storm drain inlet. Curbs are typically installed in combination with gutters where runoff from the pavement surface would erode fill slopes and/or where right-of-way requirements or topographic conditions will not permit the development of roadside ditches (USA Department of Transportation, 2013).

Pavement sections are typically curbed in urban settings. Parabolic gutters without curbs are used in some areas.

**Drainage Inlets** are the receptors for surface water collected in ditches and gutters, and serve as the mechanism whereby surface water enters storm drains. When located along the shoulder of the roadway, storm drain inlets are sized and located to limit the spread of surface water onto travel lanes. The term "inlets," as used here, refers to all types of inlets such as grate inlets, curb inlets, slotted inlets, etc.

Drainage inlet locations are often established by the roadway geometries as well as by the intent to reduce the spread of water onto the roadway surface. Generally, inlets are placed at low points in the gutter grade, intersections, crosswalks, cross-slope reversals, and on side streets to prevent the water from flowing onto the main road. Additionally, inlets are placed upgrade of bridges to prevent drainage onto bridge decks and downgrade of bridges to prevent the Flow of water from the bridge onto the roadway surface (USA Department of Transportation, 2013).

Ditches collect surface runoff from surrounding plots and roads (Jeanne Dollinger, Et al., 2016). The amount of runoff collected by ditches depends on the runoff that is produced in connected areas andon the ability of the ditches to capture it. In semi-arid areas, surface runoff fluxes may constitute the major proportion of the total water flow in ditch networks whereas this proportion is reduced under continental humid climates (Jeanne Dollinger, Et al, 2016).

The ability of ditches to capture runoff fluxes is related to several ditch characteristics. The ditch morphology determines its storage capacity and the surface area of the connected zones where runoff is generated (Levavasseur F, et al. , 2012). The locations of the ditches within the watershed and their orientation with regard to the slope impact their interception efficiency, which is greater if the ditches are perpendicular to the slope (Carluer N, Marsily G , 2004). The designs of ditch networks, including reach morphology, reach branching, and density, are also strongly related to the runoff capture efficiency (Levavasseur F, et al. , 2012).

Storm drain inlets are used to collect runoff and discharge it to an underground storm drainage system. Inlets are typically located in gutter sections, paved medians, and roadside and median ditches (ERA, 2013).

### 2.6.3 Storm water Discharge Controls

Storm water discharge controls are often required to off-set potential runoff quantity and/or quality impacts. Water quantity controls include detention/retention facilities. Water quality controls include extended detention facilities as well as other water quality management practices.

**Detention/retention** facilities are used to control the quantity of runoff discharged to receiving waters. A reduction in runoff quantity can be achieved by the storage of runoff in detention/retention basins, storm drainage pipes, swales and channels, or other storage facilities. Outlet controls on these facilities are used to reduce the rate of storm water discharge. This concept should be considered for use in highway drainage design where existing downstream receiving channels are inadequate to handle peak flow rates from the highway project, where highway development would contribute to increased peak flow rates and aggravate downstream flooding problems, or as a technique to reduce the size and associated cost of outfalls from highway storm drainage facilities (ODOT, 2014).

**Water quality controls** are used to control the quality of storm water discharges from highway storm drainage systems. Water quality controls include extended detention ponds, wet ponds, infiltration trenches, infiltration basins, porous pavements, sand filters, water quality inlets, vegetative practices, erosion control practices, and wetlands. Classes of pollutants typically associated with highway runoff include suspended solids, heavy metals, nutrients, and organics. Water quality controls should be considered for use as mitigation measures where predictions indicate that highway runoff may significantly impact the water quality of receiving waters (USA Department of Transportation, 2013).

The objective of road storm drainage design is to provide for safe passage of vehicles during the design storm event. The design of a drainage system for a curbed road pavement section is to collect runoff in the gutter and convey it to pavement inlets in a manner that provides reasonable safety for traffic and pedestrians at a reasonable cost. As spread from the curb increases, the risks of traffic accidents and delays, and the nuisance and possible hazard to pedestrian traffic increase (ERA, 2013).

### 2.6.4 Hydraulic capacities of the different drainage elements.

The hydraulic capacity of a storm drain inlet depends upon its geometry as well as the characteristics of the gutter flow. Inlet capacity governs both the rate of water removal from the gutter and the amount of water that can enter the storm drainage system. Inadequate inlet capacity or poor inlet location may cause flooding on the roadway resulting in a hazard to the traveling public (USA Department of Transportation, 2013).

## 2.7 Construction and maintenance of drainage systems

The planned drainage systems for a project can only be finalized during the work's execution, when the local geotechnical conditions are fully understood. Thus, it is important that an adequate specification is produced for the anticipated type of drainage system and for suitable materials, so that the implementation teams are able to deliver the best solutions (Andrew Dawson, October 2008).

The many phases which constitute the construction of a road are sometimes delayed, and this can be drainage related, due to:

- Alteration in design flows;
- Obstruction of the surface and underground water flow path, due to earth moving and material placement;
- Possible surface and underground water contamination, due to earth moving, machine cleaning and associated incidents;
- Increase in the soil's compaction in the areas where there is flow to or from an aquifer; and
- Alteration in the hydrological regime, as a consequence of the disturbed soil caused by the construction of the road structure. (Andrew Dawson, October 2008).

### 2.7.1 Maintenance:

It is of great importance that the draining system is working properly, hence regular checks and maintenance are required. Every drainage system should be designed to ensure that inspection and maintenance operations are possible and accessible. Usually, the cleaning of the drainage system should be done at the end of the summer, but inspections could be intensified in periods of high precipitation.

However, at least every 5 years it is fundamental that there is a proper inspection of every part of the drainage system.

The problems that practitioners encounter are manifold. In the WATMOVE questionnaire survey (see www.watmove.org) the following issues were mentioned:

- The drainage system becomes clogged with fine materials,
- Crushed pipes,

- Poor outlet conditions, i.e. outlets have negative slopes,
- Root penetration, Generation of ferrous hydroxide and calcium carbonate,
- Insufficient capacity,
- Inadequate water velocity,
- The (plastic) cover of the inspection well at the slope may be damaged (sometimes due to snow clearance of the road).

## 2.8 The impacts of drainage underperformance

Poor road pavement can result in costly repairs or pavement replacement long before the road pavements reach their expected design life.

Additionally, excessive water/moisture content in the pavement base, subbase and subgrade can cause early distresses, i.e., rutting, fatigue cracking, raveling alligator cracking, potholes, base failures, settlement, swelling…etc. That can lead to structural and functional failures.

The following are some water-related effects: Reduce base, subbase, and subgrade strength; Differential swelling in expansive cohesive clay soils; Stripping of binder/bitumen from aggregate; Movement of "fines" into base or subbase course material causing reduction of hydraulic conductivity; Reduce pavement load bearing capacity; Washout of road segments or structures; and Reduced engineering properties of soils, i.e. cohesiveness, friction……etc.

Consequently, water combined with traffic loading can have a negative effect on both material properties and the overall performance of the road system, i.e., premature road failure. Water entering the road pavement can accelerate pavement deterioration that results in 1) increase operation and maintenance cost; 2) shorten road lifecycle, 3) poor ride quality, 4) increase accidents, 5) increase road users' delay, 6) accelerated pavement replacement and increased cost and increased vehicle users operating cost ( Prithvi S, 2002).

Roads will affect the natural surface and subsurface drainage pattern of a watershed or individual hill slope. Road drainage design has as its basic objective the reduction and/or elimination of energy generated by flowing water. Therefore, water must not be allowed to develop sufficient volume or velocity so as to cause excessive wear along ditches, below culverts, or along exposed running surfaces, cuts, or fills. Provision for adequate drainage is of paramount importance in road design and cannot be overemphasized. The presence of excess water or moisture within the roadway will adversely affect the engineering properties of the materials with which it was constructed. Cut or fill failures, road surface erosion, and weakened subgrades followed by a mass failure are all products of inadequate or poorly designed drainage. As has been stated previously, many drainage problems can be avoided in the location and design of the road: Drainage design is most appropriately included in alignment and gradient planning (Larson, et al., 1949).

The roadway shall not obstruct the general flow of surface water or stream water in any unreasonable manner to cause an unnecessary accumulation either of water flooding or water saturated uplands, or an unreasonable accumulation and discharge of surface water flooding or water saturated lowlands. The failure of road occurred on *HagereMariam* to *Yirgachefe* road due to inadequate capacity of the drainage. If the failure is sudden and catastrophic, it can result in injury or loss of life and property (O'Flaherty, C.A., 2002).

### 2.8.1 Effects of Poor Drainage system on Roads

An appropriate understanding of the dynamics of water flow in roads is important for many reasons. It is well known that the rate of road deterioration increases if the water content of the granular material increases. Presents no less than six adverse effects related to excess water: reduction of shear strength of unbound materials, differential swelling on expansive sub grade soils, movement of unbound fines in flexible pavement base and sub base layers, pumping of fines and durability cracking in rigid pavements, frost-heave and thaw weakening, and stripping of asphalt in flexible pavements. In a recently performed accelerated load test, used a Heavy Vehicle Simulator (HVS) to show that the rate of rutting increased in all layers of a flexible construction when the ground water table was raised. On the positive side, ensuring proper (optimal) water content greatly improves packing of the road during construction, and may also increase its resilience when trafficked, even though this effect is often neglected. In conclusion, initially maintaining adequate water contents in asphalt road materials is beneficial but if the water content increases with time, negative effects will most likely emerge. It is generally desired to keep the road as close to or less than optimum water content as possible over time (Diriba, 2016).

However, to realize road benefits, roads must be properly designed, constructed, operated and maintained. A key factor in effective road performance is proper drainage (Edgar Leonard , 2004).

Prithvi Singh Kandhal, associate director of the National Center for Asphalt Technology at Auburn University and internationally-recognized for work in asphalt road construction technology, noted, “It is a fundamental tenet of practicing pavement engineering that three things are vital for pavement performance: Drainage, Drainage, and Drainage.”

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Description of the study area

The project road section, *Yirgachefe - Hageremariam,* is located in the southern Ethiopia, in the Southern Nations, Nationalities and People's Region (SNNPR) and its last section is connected to the Oromia Region, Bule Hora *woreda* of Guji Zone.

*Yirgachefe* is a town in central southern Ethiopia in *Yirgachefe* District. Located in the Gedeo Zone of the Southern Nations, Nationalities and Peoples' Region, this town has an elevation between minimum 1,880 and maximum 1,919 meters above sea level. It is the administrative center of Yirgachefe woreda. Bule Hora Town (formerly Hagere Mariam) is a town is located in Oromia Region, Bule Hora woreda of Guji Zone. Located on the paved Addis Ababa-Moyale highway, in the West Guji Zone of the Oromia Region. It is the largest town in this zone mainly inhabited by the Guji Oromo. It has a latitude and longitude of 5°35′N 38°15′E and an averagely altitude of 1716 meters above sea level.

Accordingly, the geographical location as per UTM (projected) Coordinate system:

Start point of road: 37 N: E = 442752, N = 0783675

End point of the road: 37 N: E = 415841, N = 0621734

The road is 72 kilometers long and it has a width of 14 town section and 7m rural section and on average 3meters wide earthen side ditches on both sides of the road.

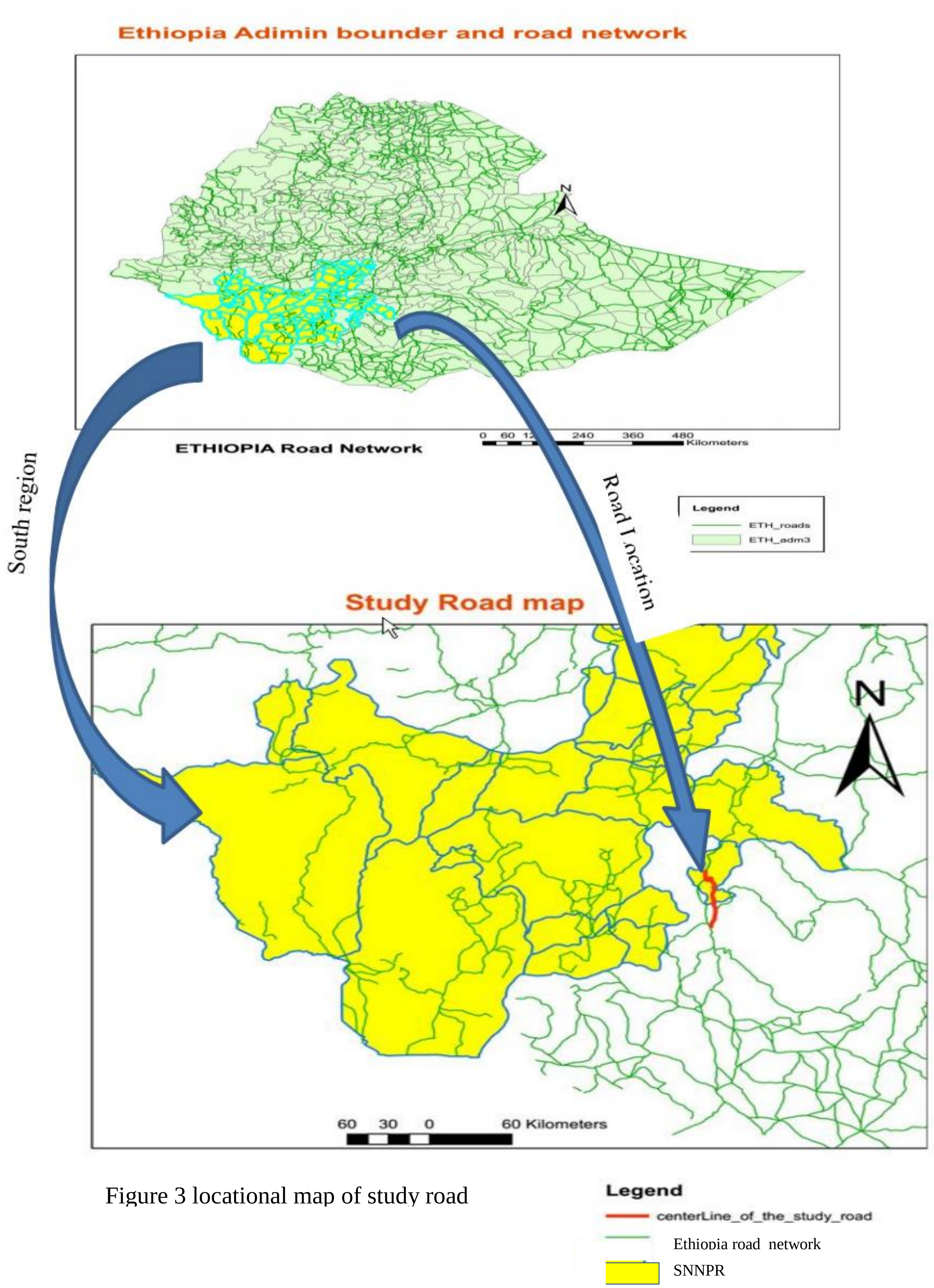


Figure 3 locational map of study road

### 3.1.1 Demography of Yirgachefe and Hageremariam

***Yirgachefe*** is one of the woredas in the Southern Nations, Nationalities, and Peoples' Region of Ethiopia, named after its major town Yirgachefe. Part of the Gedo zone, Yirgachefe is bordered on the south by Kochere, on the west by the Oromia Zone, on the north by Wonago, on the east by Bule woreda, and on the southeast by Gedeb. Coffee is an important cash crop of woredas. Based on the 2007 Census conducted by the National Census Agency (CSA), this woreda has a total population of 195,256, of whom 97,385 are men and 97,871 women; 15,118 or 7.74% of its population are urban dwellers (CSA, 2007).

**HagereMariam (Bule Hora)** is one of the woreda in the oromia region of Ethiopia. Hagere Mariam was bordered on the south by the Dawa river which separates it from Arero, on the southwest by Yabelo, on the west by the southern nation nationality and peoples region and Gelana Abaya, on the northeast by Uraga and on the east by Odashakiso. The largest town of Bule Hora is Bulehora town, formerly called Hagere Mariam. The 2007 national census reported a total population for this woreda of 264,489, of whom 133,730 were men and 130,759 were women; 35,245 or 13.33% of its population were urban dwellers. Based on figures published by the CSA in 2005, the not yet divided woreda (including today`s woredas of Bule Hora, Dugda Dawa and Kercha) had an estimated total population of 546,456, of whom 269,727 were men and 276,729 were women; 22,784 or 4.17% of its population were urban dwellers, which was less than the Zone average of 11.6%. With an estimated area of 6,021.88 square kilometers, Hagere Mariam Woreda had an estimated population density of 90.7 people per square kilometer (CSA, 2007).

### 3.1.1 Climate

The climate in Yirgacheffe is warm and temperate. In winter, there is much less rainfall in Yirgacheffe than in summer. The average temperature in Yirgacheffe is 18.4 °C. Precipitation here averages 1525 mm. March is the warmest month of the year. The temperature in March averages 19.7 °C. December has the lowest average temperature of the year. It is 17.3 °C.

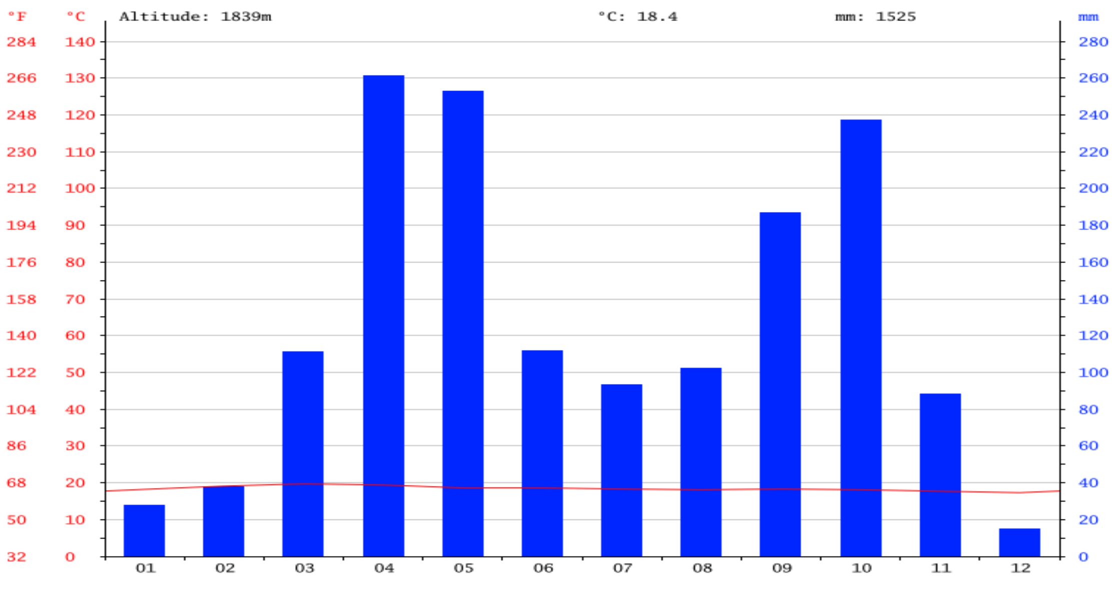


Figure 4 Average monthly climograph of Yirgacheffe (source: climate-data org)

***HagereMariam***, Ethiopia - Monthly **weather** averages including average high and low **Temperature**, **Precipitation**, Pressure, and Wind Charts to assist you in planning your travel, holiday or an outdoor activity at **Hagere Mariam**, Ethiopia.

### 3.1.2 Hydrology soil group

Soils are classified, in to four hydraulic groups: A, B, C, and D based on their runoff potential. Soil A has a low runoff potential, it has a high infiltration rate and high rate of water transmission. This group covers soils such deep sand, deep loess,, and aggregated silt. Soil B has moderate infiltration and water transmission rates. This group includes shallows loess and sandy loam. Soil C has slow infiltration and water transmission rates even if throughout wetted. This group includes layered soils with high fine texture such as clay loam, shallow sandy loam

The study area is found on the Southern part of Ethiopia. The type of soil on the study area is Nitisols (FAO, 1998) that covers almost 100% of the total soil coverage. In Nitisols about 70% of the soil is silt loam of hydrologic soil group B and the remaining 30% is clay (FAO, 1998) of hydrologic soil group C.

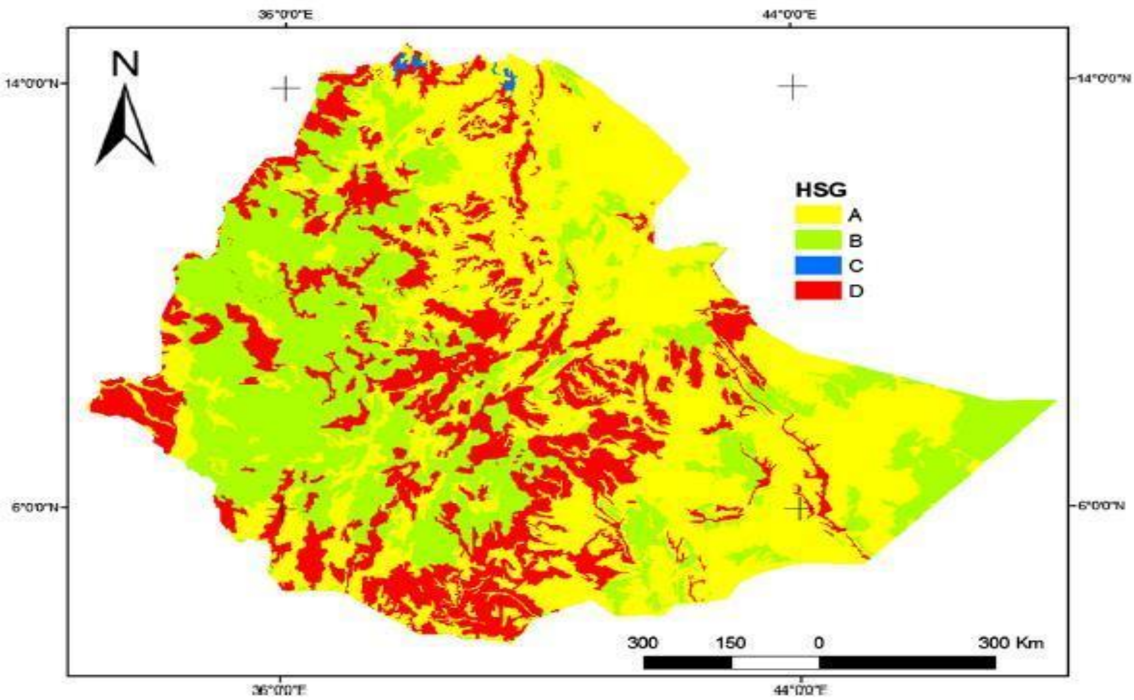


Figure 5 Hydrological soil group of Ethiopia (source: FAO soil classification)

## 3.2 Materials

- Hand GPS (geographical positioning system): used to locate measuring points.
- Measuring tape: to measure length, width and depth of drainage structures
- Soil laboratory materials like weighing balance, Oven dry and volumetric flask used for soil sample test.

- Metal box: to take sample from the field to the laboratory
- Digital camera: To take sequential pictures to show study progress and any variation
- Soil auger: also used to dug soil sample
- The materials that are used for the study of the research are digital camera, GPS device, and measuring tape. All these materials are used during field visit of the study area.
- Different softwares were used for analysis of collected data like ArcGIS, WMS, HEC-RAS and Global mapper.

## 3.3 Methods

### 3.3.1 Data collection

Information required for hydrologic and hydraulic analysis was collected. The collected data include the following

1. Digital elevation model: 15m resolutions DEM was downloaded through help of WMS software and were used for the delineation of watershed.
2. Rain fall data: rainfall data was collected from Ethiopia metrological agency
3. Survey: addition survey should be carried out for the existing culvert status

Descriptive and exploratory types of research are used for this thesis. The descriptive type of research is used to describe the existing performance condition whereas exploratory type of research is used to explore the existing performance condition of drainage structures.

Topography field visiting of the study area is carried out to determine existing performance condition of drainage structures. Observing flood marks, measuring the size of the existing drainage structures, measuring the elevation difference between river or stream bed and flood mark as well as gathering information is carried out about the overall performance of drainage structures during the rainy season.

The mathematical equations that are used to determine peak discharges are Rational and SCS equations. Recommendations in ERA 2013 drainage design manuals are used to determine peak discharges. These manuals are the lead information documents and main reference tools for this thesis work.

### 3.3.2 Site assessments

An important first step in the design of a culvert is a comprehensive understanding of the site and conditions where the culvert will be located. Other concerns include how a culvert might impact roadside safety when a vehicle leaves the roadway, or create hazardous conditions for children in urban areas. The safety of errant vehicles should be provided for by the appropriate location and design of culvert inlets and outlets. Safety barriers and grates may substitute or add to this protection.

#### 2.3.1.1 Environmental concerns

The thesis, work with other disciplines to devise and construct mitigation measures which reduce adverse effects. May also identify spoil disposal areas and geometry, and various construction alternatives. They may also assist in developing programs for protecting surface waters during construction. In addition methods to reduce erosion and sedimentation would also be proposed.

### 3.3.3 Hydrology

#### 3.3.2.1 Low Flow Discharges

Construction and maintenance of highways may require knowledge of low flow discharge properties such as discharges, flow stages, flow durations and related flow variables. For example, the construction of a culvert or a bridge may require knowledge of the time frame at which flows are below certain levels, or below certain magnitudes. This knowledge might be useful in scheduling construction (wet or dry season), or designing temporary construction facilities. With some facilities it is often necessary to avoid long periods where the facilities are unavailable to the user due to prolonged occupation of a portion of the facility by frequent low flows.

### 3.3.4 Catchment area

A catchment area is determined from topographic maps; DEM data’s and field surveys. For large catchment areas it might be necessary to divide the area into sub-catchment areas to account for major land use changes, obtain analysis results at different points within the catchment area, or locate storm water drainage structures and assess their effects on the flood flows. A field inspection of existing or proposed drainage systems shall be made to determine if the natural drainage divides have been altered. These alterations could make significant changes in the size and slope of the sub catchment areas.

### 3.3.5 Hydrologic analysis method

Stream flow measurements for determining a flood frequency relationship at or near a site are usually unavailable. In such cases, it is an accepted practice to estimate peak runoff rates and hydrographs using flow estimation methods. In general, results from using several methods should be compared, not averaged. The discharge that best reflects local project conditions, with the reasons documented, should be used.

The peak discharge is adequate for design of conveyance systems such as storm drains, open channels, culverts, and bridges. However, if the design necessitates flood routing through areas such as storage basins and complex conveyance networks, a flood hydrograph is required. Many hydrologic methods are available for estimating peak discharges and runoff hydrographs.

Each method has a range of application and limitations, which the engineer should clearly understand prior to using them. Basin size, hydrologic and geographic region, dominant precipitation type, elevation, and level of development are all important factors. appropriate for the basin conditions and that sufficient data is available to perform the required calculations. Several methods will be appropriate for predicting peak flood rates and volumes at most sites.

The following methods and sources can be used in determining peak flood magnitudes for design of road drainage structures in this theses work.

The following are some of the most widely used and used in this thesis flow estimation methods:

• Rational Method;

• SCS Runoff Curve Number Methods;

Hydrological analysis is the most important step prior to the hydraulic design of highway drainage structure. It includes the estimation of the catchment physical parameters, calculation of time of concentration, establishment of intensity duration frequency curve and calculation of runoff.

**Estimation of catchment physical parameter**

Physical parameter of the drainage area is very significant for hydrological analysis. Boundaries of catchment are delineated from the 15m resolution DEM. The area of each catchment as well as the difference in elevation within catchment is used for computing runoff quantities. The runoff coefficient/curve number for every catchment is generally estimated from the ground cover, land use and land cover shape file of Ethiopia.

**Runoff formula**

Several methods, each with its own assumption and constraints, may be used to estimate watershed runoff. Two methods are used in preliminary analysis for estimating runoff from the drainage area crossed by project. The applications of each method depend on the availability and type of rainfall data, flow records and catchment size.

**2.3.4.1 Rational Method:**

The Rational Method provides estimates of peak runoff rates for small urban and rural watersheds of less than 50 hectares (0.5 $km^2$) and in which natural or man-made storage is small. It is best suited to the design of urban storm drain systems, small side ditches and median ditches, and driveway pipes. It shall be used with caution if the time of concentration exceeds 30 minutes. Rainfall is a necessary input for this method of flow estimation. Rational Method inappropriate for catchment areas greater than 50 hectares (ERA, 2013).

**Q = 0.278 C i A** **(3.1)**

Where

Q = maximum rate of runoff, $m^3/s$

C = runoff coefficient representing a ratio of runoff to rainfall

i = average rainfall intensity for a duration equal to the time of concentration, for a selected return period, mm/hr.

A = catchment area tributary to the design location, ha

**2.3.4.2 SCS Runoff Curve Number Methods:**

The Natural Resources Conservation Service (formerly Soil Conservation Service) developed the runoff curve number method as a means of estimating the amount of rainfall appearing as runoff. Technical Release 20 (TR 20) employs the Runoff Curve Number Method and a dimensionless unit hydrograph to provide estimation of peak discharges and runoff hydrographs from complex watersheds.

The unit hydrograph used by the SCS method is based upon an analysis of a large number of natural unit hydrographs from a broad cross section of geographic phenomenon.

However, the SCS Curve Number method is applicable to the catchments area more than 50hec (maximum area 6,500 ha) with a time of concentration for any sub-area of 0.1 – 10 hours (NRCS, 2002).

Table 2 flood estimation methods

| Method | Input data | Recommended maximum area($km^2$) | Return period of flood that could be determined (years) |
|---|---|---|---|
| Rational Method | Catchment area, watercourse length, average slope, catchment characteristics, rainfall intensity | <0.5 | 2 – 200, PMF |
| SCS Method | Catchment area, watercourse length, length to catchment Centroid(center),mean annual rainfall, veg. type ,soil cover and synthetic regional unit | 0.5 to 65 | 2 – 200, PMF |

| | | | |
|---|---|---|---|
| | hydrograph | | |

The united states Soil Conservation Service (SCS – now the Natural Resource Conservation Service) method estimates runoff using in addition to rainfall, catchment characteristic such as antecedent soil moisture conditions, types of soil, initial abstraction of rainfall, slope, length of the longest channel, and surface treatment sand land cover. The characteristics are reflected by a curve number value.

This number typical range from 25 (for low runoff depression) to 98 (for paved impervious area). An initial abstraction factor (Ia) can be specified. The SCS-CN method typically used an initial abstraction of 0.2S, where S is maximum soil storage depth (in inches) and is calculated from the equation below (other value may be used)

$$S = \frac{1000}{CN} - 10 \qquad (3.2)$$

Where: CN = Curve Number

S = maximum storage depth

Soils are classified, in to four hydraulic groups: A, B, C, and D based on their runoff potential. Soil A has a low runoff potential, it has a high infiltration rate and high rate of water transmission. This group covers soils such deep sand, deep loess,, and aggregated silt. Soil B has moderate infiltration and water transmission rates. This group includes shallows loess and sandy loam. Soil C has slow infiltration and water transmission rates even if throughout wetted. This group includes layered soils with high fine texture such as clay loam, shallow sandy loam

### 3.3.6 Time of concentration

Hydrologic methods require an estimation of the time of concentration. The time of concentration (Tc) is used in the Rational Method to determine the critical rainfall duration, which can then be combined with an appropriate rainfall intensity duration frequency (IDF) relation to establish the required design rainfall intensity. The Tc is the time required for water to flow from the most remote point of the basin to the location being analyzed.

The Kirpich and Kerby equations are widely used to estimate time of concentration (Channel flow), U.S. SCS formula is presented.

$$\boldsymbol{Tc = 0.604(\frac{RL}{S^{0.5}})^{0.462}} \qquad \textbf{(3.3)}$$

Where: Tc – Time of concentration in hours

L – Length of overland flow in kilometers

S – Slope in m/m

R – Roughness coefficient

$$\boldsymbol{Tc = 0.0013m(\frac{L^{0.77}}{S^{0.385}})} \quad \textbf{(3.4)}$$

Where, Tc – Time of concentration in hours

L – Length of overland flow in kilometers

S – Slope in m/m

m- Earth type coefficient

Time of concentration is the time it takes water to flow from the edge of the catchment area to the point of interest. It is a combination of three values in SCS method of determining peak flow rate.

A. Sheet flow,

B. Shallow concentrated flow, and

C. Open channel flow

The type that occurs is a function of the conveyance system and is determined by field inspection. It is often a combination of these flows so that the total travel time is the sum of the time taken for the water to pass through all of the segments of the catchment. Travel time is the ratio of flow length to flow velocity:

$$\boldsymbol{T = \frac{L}{3600V}} \quad \textbf{(3.5)}$$

Where: T = travel time, hr

L = flow length, m

V = average velocity, m/s

The U.S. SCS formula to estimate time of concentration is:

$$\boldsymbol{Tc = [\frac{0.87L^2}{1000Sav}]^{0.385}} \quad \textbf{(3.6)}$$

Where, Tc – Time of concentration in hours

Sav – Average slope in m/m

L – Hydraulic length of catchment along the flow path from the catchment boundary to the place

where the flood needs to be determined (km).

Travel time is the time it takes water to travel from one location to another in a catchment area.

Tt is a component of time of concentration.

Tc=Tt1+Tt2+----+Ttn

1. Sheet Flow

In sheet flow, travel time is determined by Manning’s kinematic solution. The

Manning's kinematic solution is expressed as:

$$\boldsymbol{Tt = [0.09(nL)^{0.8}/(p2)^{0.5}S^{0.4}]} \quad \textbf{(3.7)}$$

Where, Tt=travel time, hr

n= Manning's roughness coefficient

L=flow length, m

P2 = 2-year, 24-hour rainfall, mm

S = Slope of hydraulic grade line (land slope), m/m

According to ERA DDM 2013, the Manning's kinematic solution is based on the following criteria.

i. Shallow steady uniform flow

ii. Constant intensity of rainfall excess

iii. Rainfall duration of 24-hours

iv. Minor effect of infiltration on travel time

2. Shallow Concentrated Flow

After a maximum of 100 meters, sheet flow usually becomes shallow concentrated flow (ERA DDM, 2013). The average velocity for this can be determined by the following formulae according to the type of surface which water flows i.e. paved and unpaved. In these formulae, average velocity is a function of watercourse slope and type of channel.

Unpaved Surface: $V = 4.9178(S)^{0.5}$

**Paved surface:** $\boldsymbol{V = 6.1961(S)^{0.5}}$ **(3.8)**

According to ERA DDM 2013 these two formulae are based on the solution of Manning's equation with different assumptions for n (Manning's roughness coefficient) and R (hydraulic radius, meter) for paved areas, the value of n is 0.025 and R is 0.06.

### 3.3.7 Data types and sources

Quantitative as well as qualitative data types were employed. Of the total data about 90% of the research data collects from primary sources. Whereas the rest 10% will collects from secondary data sources-this employ to reinforce the primary data source.

### 3.3.8 Data collection methods

**Primary data source:** The research is conducted first by identification of the causes of road drainage problems through literature review and desk study on selected road drainage problem on the study area.

**Site visit/observations:** site visit was carried out to ascertain current conditions poor drainage system in this road in comparison with the acceptable standards. The researcher use a physical observation checklist, which was filled through observations and a digital camera will used to take photographs of the current state of the road and the drainage system, Field survey measuring the data by using tape and GPS.

Questionnaire was a research instrument consisting of a series of questions and other prompts for the purpose of gathered information from respondents. Asking the contractors and people living around the study area and interviews means Oral questions will be asked to get more information and to clarify the ambiguous response. The study area information that will gathered from the residences and road user. Interview helps to employ to collect data related to flooding hazards and causes of flooding through household survey.

**Secondary data source**: the data from different written documents and topographical map, published and unpublished data, internets.

**Photography**:-Photography is an indirect way of data collection. It will majorly use to capture the current status of the drainage system in HagereMariam to Yirgachefe road. It will meant to give a visual understanding of the research topic to the readers of this research project, the extent of deterioration, maintenance and the state of the drainage system.

### 3.3.9 Rainfall-runoff equation

The SCS method is based on a 24-hour storm event. The characteristics of storms defined in terms of the relationship between the percentages of the total storm rainfall that has fallen as a function of time.

The SCS 24-hour storm distributions are based on the generalized rainfall depth-duration-frequency relationships collected for rainfall events lasting from 30 minutes up to 24 hours. Working in 30-minute increments, the rainfall depths are arranged with the maximum rainfall depth assumed to occur in the middle of the 24-hour period.

A relationship between accumulated rainfall and accumulated runoff derived by SCS for numerous hydrologic and vegetative cover conditions are important for peak discharge determination. The storm data included total amount of rainfall in a calendar day but not its distribution with respect to time. The SCS runoff equation is therefore a method of estimating direct runoff from 24-hour storm rainfall (ERA DDM).

$$\boldsymbol{Q = \frac{(P - Ia)^2}{(P - Ia) + S}} \qquad \textbf{(3.9)}$$

For P>0.2S

Q =0 for P≤0.2S

Where:

Q = accumulated direct runoff, mm.

P = accumulated rainfall (i.e., the potential maximum runoff), mm.

Ia = initial abstraction (surface storage, interception, and infiltration prior to runoff), mm.

S = potential maximum retention, mm.

S is a site index defined as the maximum possible difference between P and Q as P⇒∞, P-Ia is called "effective rainfall". It is related to the soil and cover conditions of the catchment area through the curve numbers. The curve number is a transformation of potential maximum retention (NRCS, 2004).

$$\boldsymbol{CN = \frac{1000}{\frac{S}{25.4}+10}} \qquad \textbf{(3.10)}$$

$$\boldsymbol{S = 25.4[\frac{1000}{CN} - 10]} \qquad \textbf{(3.11)}$$

S is in millimeter

The relationship between Ia and S was found to be;

**Ia= 0.2S** **(3.12)**

Equation 3 Substituting in to Equation 5

$$\boldsymbol{Ia = 50.8[\frac{100}{CN} - 1]} \qquad \textbf{(3.13)}$$

$$\boldsymbol{Q = \left[P - 50.8\left(\frac{100}{CN} - 1\right)\right]^2 / [P + 203.2\left(\frac{100}{CN} - 1\right)]} \qquad \textbf{(3.14)}$$

### 3.3.10 Open channel flow

Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where blue lines (including streams) appear on Ethiopian Mapping Agency (EMA) topographic maps(1:50,000). Average velocity is usually determined for bank-full elevation. Manning's equation or water profile information used to estimate average flow velocity. When the channel section and roughness coefficient are available, then the average velocity can be calculated by using manning's equation.

$$\boldsymbol{V = (R^{2/3}S^{1/2})/n} \qquad \textbf{(3.15)}$$

$$\boldsymbol{R = A/P} \qquad \textbf{(3.16)}$$

After average velocity is calculated, Tt is calculated by using equation (3.9)

$$T_c = T_{t1} + T_{t2} + T_{t3} \qquad (3.17)$$

Where, $T_{t1}$=travel time for sheet flow

$T_{t2}$=travel time for shallow concentrated flow

$T_{t3}$ =travel time for open channel flow

Using the calculated time of concentration, unit peak discharge is obtained from Appendix B on Figure 17. After unit peak discharge is obtained, design peak discharge is determined using the formula:

$$\textbf{Design Peak Discharge, } Q_p = Qu * Q * A \qquad (3.18)$$

Where, $Q_p$ = Design Peak Discharge, $m^3/sec$

Qu =Unit Peak Discharge, $m^3/sec/100ha/mm$

Q = Direct Runoff, mm

A = Area of the catchment, ha

### 3.3.11 Runoff and Curve Numbers

The physical catchment area characteristics affecting the relationship between rainfall and runoff (i.e. the CN values) are land use, land treatment, soil types, and land slope.

Land use is the catchment area cover and it includes agricultural characteristics, type of vegetation, water surfaces, roads and roofs. Land treatment applies mainly to agricultural land use, and it includes mechanical practices such as contouring or terracing and management practices such as rotation of crops. The SCS method uses a combination of soil conditions and land-use to assign a runoff factor (curve number) to an area. These runoff factors or curve numbers (CN), indicate the runoff potential of an area. The higher the CN, the higher is the runoff potential.

To describe these curves mathematically, SCS assumed that the ratio of actual retention to potential maximum retention is equal to the ratio of actual runoff to potential maximum runoff, the latter being rainfall minus initial abstraction. In mathematical form, this empirical relationship is

$$\frac{F}{S} = \frac{Q}{P - Ia} \qquad (3.19)$$

Where, F = actual retention (mm)

S = potential maximum retention (mm)

Q = accumulated runoff depth (mm)

P = accumulated rainfall depth (mm)

Ia = initial abstraction (mm)

After runoff has started, all additional rainfall becomes either runoff or actual retention (i.e. the actual retention is the difference between rainfall minus initial abstraction and runoff).

$$\boldsymbol{F = P - Ia - Q} \qquad \textbf{(3.20)}$$

The potential maximum retention S has been converted to the Curve Number CN in order to make the operations of interpolating, averaging, and weighting more nearly linear. This relationship is

### 3.3.12 Data analysis

The collected data were analyze with the help of Microsoft excel, ArcGIS, HEC-RAS and WMS.

**HEC-RAS**

HEC_RAS is an integrated system of software, designed for interactive use in a malt-tasking environment. The system is comprised of a graphical user interface (GUI), separate analysis components, data storage and management capabilities, graphics and reporting facilities.

In this research this software will used for analysis of bridge and culverts with help of x-section data.

**ArcGIS**

GIS will used for Watersheds delineated, also known as basins or catchments, are physically delineated by the area upstream from a specified outlet point. The required data, which includes a digital elevation model (DEM) and stream network file for the area of interest. Note that the global data explorers have released many of the data outputs that are created in this process as a packaged available free.

**WMS (watershed management system)**

As an interface for hydraulic modeling that supports HEC-RAS, the ability to couple hydrologic and hydraulic models for flood plain studies, and an interface to a storm drain hydraulic model used by the FHWA. A Storm Drain model for the design and analysis of storm drain networks is also a part of the WMS 10.1.

Hydrological analysis was carry out by using Rational and SCS equations. Hydraulic parameters are determined by using Manning's equation. And model different structures of drainage like bridge, culvert and pipe with the help of above software.

Peak discharge estimated by the "rational" method or formula and is recommended for use on channels draining less than 50 hectares.

$$\mathbf{Q = 0.278\ C\ i\ A} \qquad \textbf{(3.21)}$$

where: Q = peak discharge, (m3/s)

i = rainfall intensity (mm/hr)

A = drainage area (km²).

If there are existing roads in the watershed, examination of the performance of existing culverts often serves as the best guide to determining the type, size, and accompanying inlet/outlet improvements needed for the proposed stream crossing. For estimating stream flow on many forest watersheds, existing culvert installations may be used as "control sections". Flow can be calculated as the product of water velocity (V) and cross-sectional area (A):

$$\mathbf{Q = A * V} \qquad \mathbf{(3.22)}$$

### 3.3.4 Intensity duration frequency analysis method

Intensity duration frequency (IDF) analysis is used to capture the essential characteristics of point rainfall for shorter durations. IDF analysis provides a convenient tool to summarize regional rainfall information.

The intensity duration frequency analysis starts by gathering time series records of different durations. After time series data is gathered, annual extremes are extracted from the record for each duration. The annual extreme data is then fit to a probability distribution in order to estimate rainfall quantities. The fit of the probability distribution is necessary in order to standardize the character of rainfall across stations with widely varying lengths of record.

Gumbel's extreme value distribution is used to fit the annual extremes rainfall data. The Gumbel probability distribution has the following form

$$X_T = \bar{X} + K_T S \qquad (3.23)$$

Where $X_T$ represents the magnitude of the T-year event, $\bar{X}$ and S are the mean and standard deviation of the annual maximum series, and $K_T$ is a frequency factor depending on the return period, T. The frequency factor is obtained using the relationship:

$$K_T = \frac{-\sqrt{6}}{\pi}[0.5772 + \ln\left(ln\left(\frac{T}{T+1}\right)\right)] \qquad (3.24)$$

Meteorological agency of Ethiopia data record shows minimum daily available but IDF curve uses to estimate rainfall frequency for durations of 5, 10, 15 and 30 minutes, as well as for 1, 2, 6, 12 and 24 hours.

However, most stations do not have data records for durations shorter than 24 hour, and therefore character of shorter rainfall durations must somehow be estimated.

World Meteorological Organization (WMO, 1994) however, provides one such method, where:

*Average ratios of rainfall amounts for 5-, 10-, 15- and 30-minutes to one-hour amounts, computed from hundreds of station-years of records, are often used for estimating rainfall-frequency data for these short durations. These ratios, which have an average error of less than 10 per cent, are:*

| | | | | |
|---|---|---|---|---|
| Duration (min) | 5 | 10 | 15 | 30 |
| Ratio (n-min to 60- mi | 0.29 | 0.45 | 0.59 | 0.79 |

Use of the above method implies that if 10-year one-hour rainfall is 70 mm, the 10-year 15-minutes rainfall is $0.59 * 70 \approx 40mm$

The IDF data derived with above methods is typically fitted to a continuous function in order to make the process of IDF data interpolation more efficient. In order to obtain this information, the Ontario Drainage Management Manual (MTO, 1997)recommends fitting the IDF data to the following three parameter function:

$$i = \frac{A}{(t_d+B)^C} \qquad (3.25)$$

Where $i$ is the rainfall intensity (mm/hr), $t_d$ the rainfall duration (min), and A, B, and C are coefficients. After selecting a reasonable value of parameter B, method of least squares is used to estimate values of A and C. The calculation is repeated for a number of different values of Bin order to achieve the closest possible fit of the data. Details of this procedure are provided in (MTO, 1997) Chapter 8. After IDF data is fitted to the above function, plots of rainfall intensity vs. duration (for each return period) can be produced. For interested reader refer (Predrag Prodanovic, Et, al, 2007) and (Ven Te Chow, 1988).

#### 3.3.5 Data presentation

The analyzed data present in tables, graphs, charts and percentages.  Besides, GIS, HEC-RAS and CAD figures also field survey photos were incorporate.

And modeled structures were in comported in the document blow.

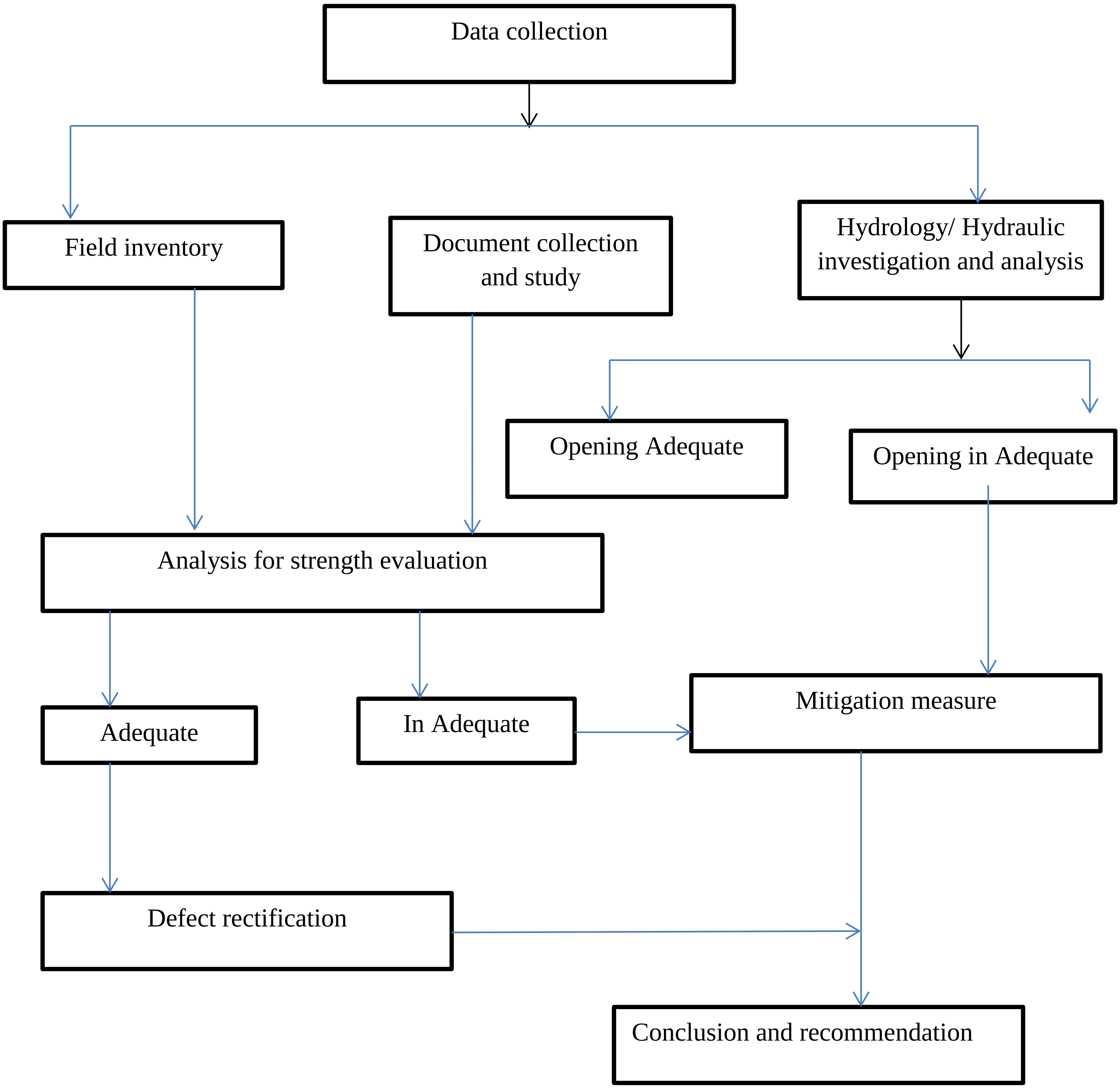


**Figure 6 methodology flow chart for evaluation of existing structure**

# CHAPTER FOUR
# Results and Discussion

## 4.1 Results from questionnaires analysis

Questionnaires were well-arranged to the engineers at the construction site, Beza consultants and the left questionnaires for dwellers around the road and road user of Hageremariam toYirgachefe road. The questionnaire comprised of open ended and structured questions on issues that are related to the study (see appendix A).

Table 3 Response rate

| Respondent | No. of planned questionnaires | | The response | The response rate (%) |
|---|---|---|---|---|
| Engineers | 8 | | 6 | 75 |
| Road user | Min bus | 6 | 21 | 70 |
| | Small bus | 6 | | |
| | bus | 6 | | |
| | Small truck | 6 | | |
| | Medium truck | 6 | | |
| | Sub Total | 30 | | |
| Resident | 50 | | 50 | 100 |
| Total | 88 | | 67 | 76 |

### 4.1.1 Challenge of drainage fallers on the asphalt pavement, response from the Engineers

The improper and no well-maintained of the drainage system are causes the failure of road pavement and it reduce their life span. This bad condition of the side drain and its structures remains the same throughout the rain season causing the runoff water to flow on the surface of the road and unable to run off through the path far from the failed drain. The resultant effect of this critical situation causes serious distresses and damages on pavement. The road edges suffered from detachment of asphalt layer due to continuous contact of water leading to stripping of asphalt from aggregates resulting in severe pavement distresses of cracking, potholes and failure of edges of the road.

The impact of poor drainage condition on road pavement is very adverse. It causes pavement distresses and deterioration which affect the safety and riding quality on the pavement. The study investigated cases of pavement failures and damages due to poor drainage experienced during the rainy season.

### 4.1.2 The effects of drainage fallers system on the road.

- ✓ Reducing the load carrying ability of the subgrade, sub base, asphalts and shoulder of the road.
- ✓ Eroding the road side surface by washing away the top surface of the road.

✓ Runoff the road and block a road by deposited waste material on the road and water

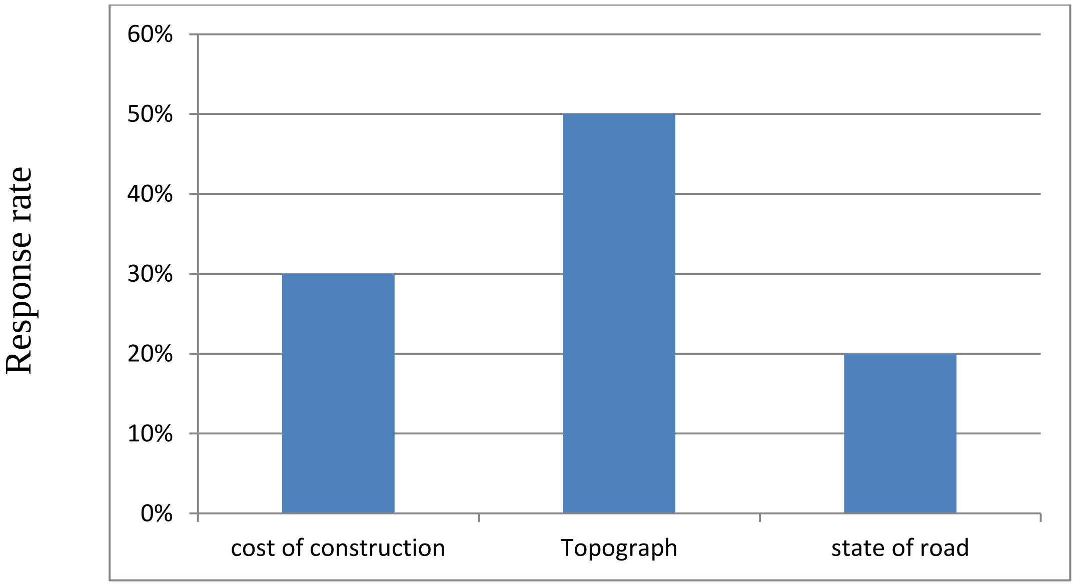


**Figure 7 Considerations when coming up with a road design.**

According to get the information from the engineers and DDM of ERA when design and construction of the road drainage structure it must be consider more on the topography of around the study area based on the location of settlements of road that useful for road user and residents in the way which to control the causes and effects of poor drainage on the road. And also consider the cost of construction and state of the road. It was important to know the critical factors considered when designing a road drainage system. This is because they helped to understand the reasons behind the design of every road.

Table 4 causes and mitigation measure of poor drainage on the road as reported in questionnaire responses.

| Problems | Causes | Effects | Solution or action |
|---|---|---|---|
| **poor quality of construction** | Lack of improper location of drainage installations | Inefficient planning and performance of measures | Overview of location of existing road drainage facilities in the local area |
| | Lack of drainage structures | Scouring/eroded shoulder | Properly construct road with all structures |
| | Number of cross drainage | Over flowing out on road surface | Add necessary crossing drainage at damaged road |

| | | | |
|---|---|---|---|
| **construction and design** | Lack of drainage capacity/improper design | Water infiltration in cracking which weakening the road | To provide the proper drainage system that increases the life of roads |
| | Improper depth of drainage installations | Inefficient drainage | Better construction /installation method. Deep drainage |
| | Limited diameter of pipe or culvert | Insufficient capacity to handle large water volumes | Consideration of the need of locally increased drainage structure dimensions |
| | Heavy precipitation; flooding | Various kinds of damage | Development and usage of tools to locate vulnerable points and need of action; addition/retrofitting of devices to increase discharge capacity, such as extra culverts, pipes, flushing pipes and subgrade drains |

It was important to know the critical factors considered when designing a road drainage system. This is because they helped to understand the reasons behind the design of every road and in this case, Hageremariam to Yirgachefe.

### 4.1.3 Effects of drainage underperformance on asphalt road, response from road users

A significant proportion of the respondents either use the road every day or twice a week. The data collected shows that 80% of the respondents use the road often. This was important to this study as it showed that the respondents could be relied on to give authentic information to achieve the studies objectives.

The road users were concerned about their safety and the convenience of going through Hageremariam to Yirgachefe road during the rains. The state of the drainage system compromised their safety as they travelled. Only 20% think the drainage system provided in Hageremariam to Yirgachefe road is good, whereas, there was none of the respondents who thought the drainage system was very poor that causes the damage of the road eroded, cracking, wash away by over flooding of the water and deposited waste materials on the road.

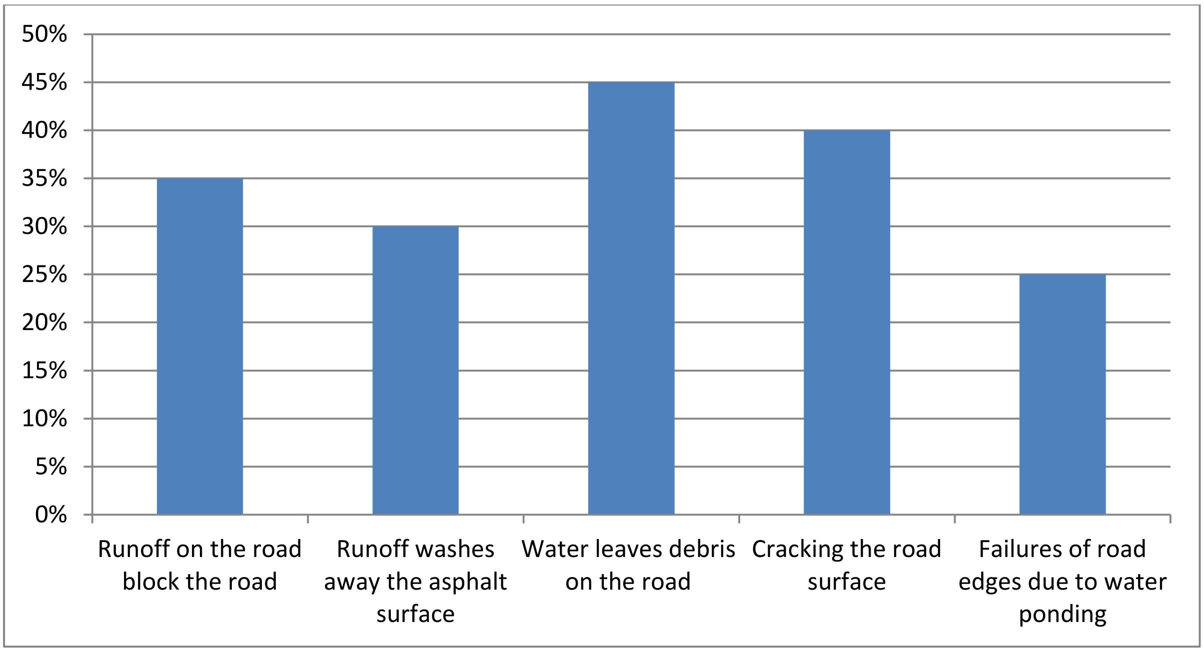


**Figure 8 Effects of poor drainage system on the asphalt pavement road.**

Road users were in consensus when it came to the effects of the poor drainage system on the road. Majority reported that the causes and effects of poor drainage on the road are water leaves debris on the road surface during the rains there by hindering free movements of vehicles on the road. It also washed away the asphalts during the rainy season, therefore totally making it impossible the passage of the road. A significant proportion reported that runoffs on the road block and cracking the through the road and leave debris on the road after the rains; this debris would then hinder movement along the road and therefore inconvenience travelers. The travelers would then become late in their businesses or other engagements.

According to the questionnaire answers, clogging of drainage pipes, culverts and ditches by debris flow and fine-grade soil is one of the most important maintenance issues in current drainage systems. Some of the respondents stated that cleaning of drainage pipes, culverts and ditches is not specified at a certain time and is therefore only done when needed. This suggests that it is important to perform operations such as maintenance and cleaning regularly to prevent over flooding of the water on the road.

### 4.1.4 Lack of community awareness to environmental management

Community awareness is one of the best proactive measures for the sustainable drainage management. Unfortunately, from the interview it was studied about 44% (22 out of 50 people) of the residents thought that damping wastes in to the natural water ways and storm water drainage system is the right thing so as to keep their homes clean and they don't even know what is wrong with the idea of dumping waste outside their home as long as their residence is clean. The other 56% of the residents knew that damping liquid wastes in to existing drainage system and water ways is wrong however, they have been enforced to damp the wastes in to the water ways irrespective of the effects that could cause to their environment. They have implied that there is no proper sewage system to collect wastes extracted from each household. From the observation it was realized that even though few people have the awareness, the authority should create awareness among the communities and also should provide proper waste management technique.

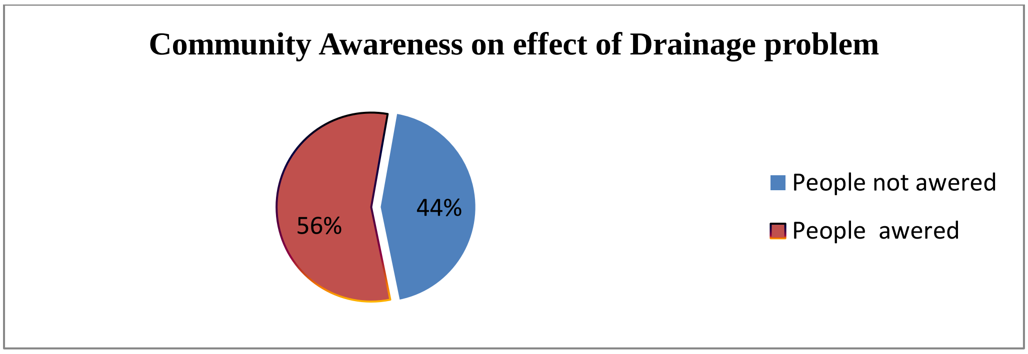


Figure 9 Community awareness on effect of drainage problem

### 4.2 Digital Elevation Model analysis result

High-resolution digital elevation (15m) data from watershed modeling system 10.1 downloaded for required catchments area are used to examine the effect of digital elevation model (DEM) grid size on the portrayal of the land surface and hydrologic simulations. Elevation data were gridded at 10m scales to generate a series of simulated landscapes. Frequency distributions of slope drainage area per unit contour length and the topographic index were calculated for each grid size model.

During analysis of DEM with help of global mapper the result of table blow was drawn out. Throughout the 72km road total catchment area wich contribute the runoff for required point as shown below table 3.3. catchment ID=5 shows the starting point of road at Yirgachefe and catchment ID=112 show the last section of study road called Hageremariam.

Table 5 Catchment parameters

| **CATCH. ID** | **FLOW DIR.** | **CATCH. AREA** | **CATCH. Hec** | **METHOD Qd** | **LAND USE CUVER** | RAINFAL REGION |
|---|---|---|---|---|---|---|
| Catchment ID=5 | RIGHT | 2.338 sq km | 233.8 | scs cn method | residential | B2 |
| Catchment ID=8 | RIGHT | 6.593 sq km | 659.3 | scs cn method | intensively cultivated | B2 |
| Catchment ID=16 | RIGHT | 7.455 sq km | 745.5 | scs cn method | intensively cultivated | B2 |
| Catchment ID=17 | LEFT | 9.986 sq km | 998.6 | scs cn method | intensively cultivated | B2 |
| Catchment ID=22 | LEFT | 11.188 sq km, | 1118.8 | scs cn method | intensively cultivated | B2 |
| Catchment ID=33 | RIGHT | 14.105 sq km, | 1410.5 | scs cn method | intensively cultivated | B2 |
| Catchment ID=37 | RIGHT | 7.872 sq km, | 787.2 | scs cn method | open shrubland | B2 |
| Catchment | LEFT | 11.188 sq km | 1118.8 | scs cn method | open shrubland | B2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| ID=22 | | | | | | |
| Catchment ID=23 | RIGHT | 5.541 sq km | 554.1 | scs cn method | open shrubland | B2 |
| Catchment ID=44 | RIGHT | 0.434 sq km | 43.4 | rational method | intensively cultivated | B2 |
| Catchment ID=34 | LEFT | 0.102 sq km | 10.2 | rational method | intensively cultivated | B2 |
| Catchment ID=47 | LEFT | 3.378 sq km | 337.8 | scs cn method | intensively cultivated | B2 |
| Catchment ID=34 | RIGHT | 16.102 sq km | 1610.2 | scs cn method | intensively cultivated | B2 |
| Catchment ID=47 | LEFT | 35.378 sq km | 3537.8 | scs cn method | intensively cultivated | B2 |
| Catchment ID=61 | RIGHT | 15.923 sq km, | 1592.3 | scs cn method | intensively cultivated | B2 |
| Catchment ID=62 | RIGHT | 7.491 sq km, | 749.1 | scs cn method | intensively cultivated | B2 |
| Catchment ID=69 | RIGHT | 12.593 sq km | 1259.3 | scs cn method | intensively cultivated | B2 |
| Catchment ID=88 | RIGHT | 0.939 sq km | 93.9 | scs cn method | intensively cultivated | B2 |
| Catchment ID=93 | RIGHT | 0.042 sq km, | 4.2 | rational method | mixed urban or built-up land | B2 |
| Catchment ID=83 | LEFT | 33.236 sq km | 3323.6 | scs cn method | mixed urban or built-up land | B2 |
| Catchment ID=102 | RIGHT SC | 11.949 sq km | 1194.9 | scs cn method | intensively mixed urban or built-up land | B2 |
| Catchment ID=112 | RIGHT | 6.826 sq km | 682.6 | scs cn method | intensively cultivated | B2 |
| Catchment ID=118 | LEFT | 7.915 sq km, | 791.5 | scs cn method | intensively cultivated | B2 |
| Catchment ID=134 | LEFT | 32.646 sq km | 3264.6 | scs cn method | intensively cultivated | B2 |
| Catchment ID=150 | LEFT | 2.97 sq km | 297 | scs cn method | intensively cultivated | B2 |
| Catchment ID=153 | RIGHT | 2.923 sq km | 292.3 | scs cn method | intensively cultivated | B2 |
| Catchment ID=112 | RIGT | 17.826 sq km | 1782.6 | scs cn method | intensively cultivated | B2 |

The road is 72 kilometers long and it has a width of 14 town section and 7m rural section and on average 3meters wide earthen side ditches on both sides of the road.

### 4.2.1 Surface hydrologic modeling and watershed delineation

The shape of a surface determines how water will flow across it. The sample hydrologic analysis extension in ArcGIS provides a method to describe the physical characteristics of a surface. Using a digital elevation model as input, it is possible to delineate a drainage system and then quantify the characteristics of that system.

Watersheds and stream networks, created from DEMs using the sample extension, are the primary input to most surface hydrologic models. These models are used for determining the height, timing, and inundation of a flood, as well as locating areas contributing pollutants to a stream, or predicting the effects of altering the landscape. An understanding of the shape of the Earth’s surface is useful for many fields such as regional planning, agriculture and forestry. These fields require an understanding of how water flows across an area, and how changes in that area may affect that flow.

The network through which water travels to the outlet can be visualized as a tree, with the base of the tree being the outlet. The branches of the tree are stream channels. The intersection of two stream channels is referred to as a node or junction. The sections of a stream channel connecting two successive junctions, or a junction and the outlet are referred to as interior links.

### 4.2.2 Watershed delineation

A watershed is the up slope area contributing flow to a given location. The watershed is also referred to as a basin, catchment, sub-watershed, or contributing area. Watersheds can be delineated from a DEM by computing the flow direction and using watershed management system(WMS). The Watershed dialog, accessed by clicking the Watershed on the Hydrology menu, uses a raster of flow direction to determine contributing area.

The watershed can be delineated for junctions in a stream network or for individual outlet points. When the threshold is used to define a watershed the outlet points for the watershed will be the junctions of a stream network derived from flow accumulation. Therefore, a flow accumulation raster must be specified as well as the minimum number of cells that constitute a stream.

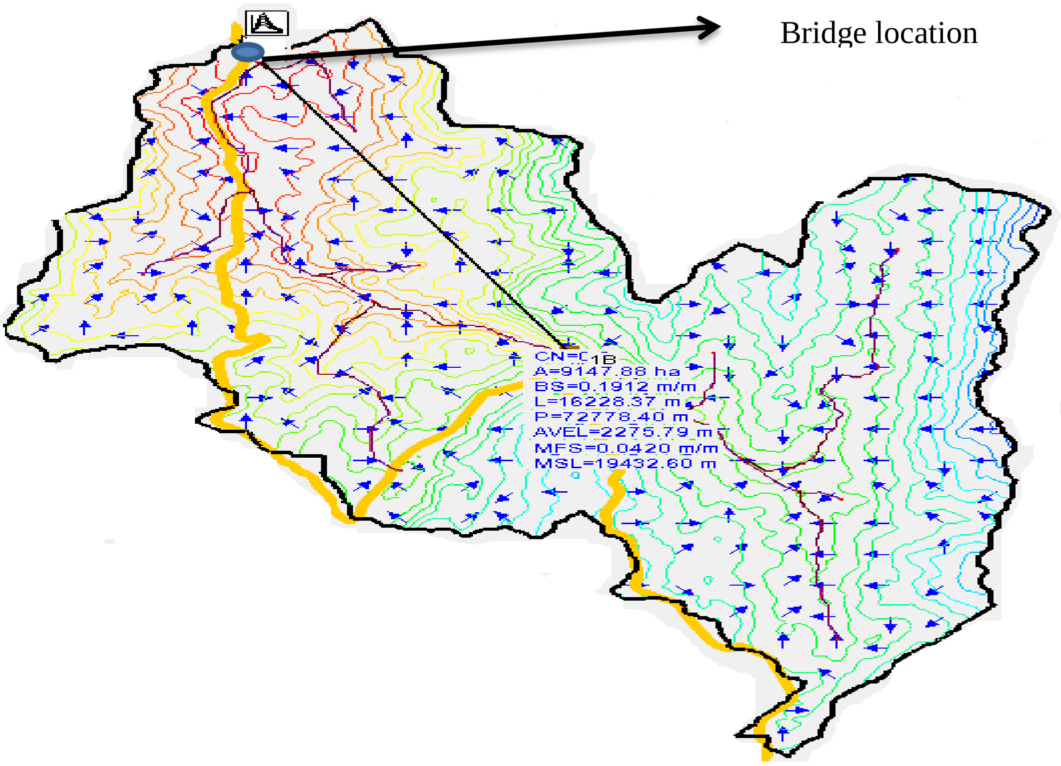


**Figure 10 flow Catchment and watershed model of existed bridge**

### 4.2.3 Hydrologic Analysis

On *Yirgachefe-Hageremariam* road, drainage structures analysis, the maximum peak flood is computed taking into consideration the road standard and the design life span of the structure.

The drainage analysis carried out existing culvert, ditch, bridges and other minor drainage structures that are found throughout the road length. Therefore, according to Appendix A in Table 13, the design and check floods are determined.

### 4.2.4 Calculation of catchment parameter

Parameter along this road at *Gedeb* town station 162+420

Using the software WMS10.1 watershed area is described and watershed properties like land use coverage, soil type, rainfall region and CN are computed. From the field surveying relatively 75% of area is cultivated and remaining 25% is covered by small trees and shrubs and scattering distributed trees. From appendix A table-14 the run of curve number for cultivated land average hydrological soil group B is 75 and soil group C is 83.5

Average CN = (0.75*75) + (0.25*83.5) =77.125 ~ nearest curve number is 75

From appendix A table 6 hydrological characteristic of soil group, the region is a wet moisture condition from appendix A table 16 CN 75avg = CN 88wet

1. 24 hour rainfall depth

Culvert at station 162+640 has diameter greater than 2m as shown on the 24hr rainfall depth for year 25 and 50 118mm for design and 132mm for checking (see appendix A table 17)

2. Direct runoff depth

From rainfall depth of 118mm for design, 132 for checking and CN= 88 and from appendix A table-18 for curve number 88 Ia= 6.9mm

$$S = 25.4\left(\frac{1000}{88}\right) - 10 = 34.6$$

From equation 3.4

$$Q_{p25} = \frac{(118 - 6.9)^2}{(118 - 6.9) + 34.6} = 84.7mm$$

$$Q_{p50} = \frac{(132 - 6.9)^2}{(132 - 6.9) + 34.6} = 97.99mm$$

3. Slope of the watershed

The average slope of the overland flow is 2.5% by referring data collected and field survey. Here blow the summary of calculation at *Gedeb* town station 162+640

Table 6 Summery of calculation along this road at Gedeb town station 162+420

| | | |
|---|---|---|
| 1 | CN | 88wet |

| | | |
|---|---|---|
| 2 | Precipitation (p) of 25yr | 118mm |
| 3 | Precipitation (p) of 50yr | 132mm |
| 4 | Potential max retention | 25.12 |
| 5 | Initial abstract (Ia) | 6.9mm |
| 6 | Direct runoff 25year (Qp25) | 84.7mm |
| 7 | Direct runoff 50year (Qp50) | 97.99mm |

### 4.2.5 Time of concentration

**Sheet flow**

Sheet flow, natural range, slope of 0.025% and length of 200m from appendix C table 21 manning roughness coefficient is n=0.035 then 2years and 24hour rainfall depth is determined from appendix B figure 18 to be 65mm. hence travel time for sheet flow is determined as:

$$Tt = 0.091(nL)^{0.8}/(P2)^{0.5}S^{0.4} = 0.013hr$$

**Shallow concentration flow**

The flow speed of paved watershed flow equation $V = 4.9178 * S^{0.5}$

$$V = 4.9178(0.025)^{0.5} = 0.7m/s$$

From equation 3.5 travel time is $Tt = \frac{L}{3600V}$ measured L=1100

$$Tt = \frac{1100}{3600(0.7)} = 0.44hr$$

**Channel flow**

Natural stream channel flow slop is 0.01 and length 1100m the bottom width measured is 2.75m and side slope 1V:2H, 25years storm depth.

$$Area = by + zx^2 = (2.75 * 1) + (1.25)(2)^2 = 7.75m^2$$

Wetted perimeter = b+2x$(1+z^2)^{0.5}$

=2.75+2*2$(1+2^2)^{0.5}$ =11.69m

Hydraulic radius(R) =A/P =5.95/7.87 =0.75m

From equation $V = \frac{R^{2/3}S^{1/2}}{n} = 1.658m/s$

$$Tt = \frac{L}{3600V} = 0.18hr$$

Total time of concentration is = $0.013hr + 0.44hr + 0.18hr = 0.63hr$

Using above Tc and year to find intensity (I) from appendix B figure 22

Ia/p = 6.9/65= 0.1

**For drainage area less than 50hec for given station**

Measured area =49hec =0.49km2

The elevation difference b/n far point of drain to outlet point 20.785m

Stream flow overland length =0.506km measured by help of software

The horizontal distance =0.498km

Slope =elevation difference/ Horizontal distance =20.785/498=0.042

Time of concentration was calculated =10.8min

Using the time of concentration and read intensity (I) from appendix B figure 22 for different return period I10 =120mm/hr., I25=145mm/hr. and I50=165mm/hr.

Runoff coeffience for agricultural wooden area= 0.2 was selected

$Q_{10} = 1 * 0.278 * I_{10}C * A = 0.278 * 120 * 0.2 * 0.49 = 3.269\, {m^3}/{s}$

$Q_{25} = 1.1 * 0.278 * I_{10}C * A = 0.278 * 145 * 0.2 * 0.49 = 4.369\, {m^3}/{s}$

$Q_{50} = 1.2 * 0.278 * I_{10}C * A = 0.278 * 165 * 0.2 * 0.49 = 5.394\, {m^3}/{s}$

By similar procedure the other station of catchments parameters were determined.

**For drainage area greater than 50he SCS CN for given station**

Measured area = 60.98hec =0.61km$^2$

Length overland flow =3250m

Horizontal distance =3.11km

Time of concentration calculated=1.03hr

Curve number was determined from land use and land cover CN=88

The hourly rainfall depth for rainfall region B2 with different return period from Appendix A table 19 is $P_{25}$=118, $P_{50}$=132 and $P_{100}$=147. From appendix A table 20 intensity for CN 88 is 6.9

Average rainfall depth of the area for required recurrence time period from rain gage data $Q_{p25}$=35mm, $Q_{p50}$=43mm and $Q_{p100}$=51mm. using time of concentration unit discharge is read from Appendix B figure 17 with time of concentration is $q_{u25}$=0.47.

Calculated peak discharge for given area

$Q_{25} = q_{u25} * Q_{p25} * A = 0.47 * 35 * 0.61 = 10.03\, {m^3}/{s}$

$Q_{50} = q_{u50} * Q_{p50} * A = 0.47 * 43 * 0.61 = 12.328\, {m^3}/{s}$

$Q_{100} = q_{u100} * Q_{p100} * A = 0.47 * 51 * 0.61 = 14.622\, {m^3}/{s}$

Above value were estimated peak flow only because no gaged site that include catchment of study area.

By similar procedure the other station of catchments parameters were determined.

## 4.3 Bridge modeling and analysis

The existing bridges that are found throughout the road length are short and medium span bridges. Therefore, according to Appendix A in Table 15 the DS3 50year life span is estimated

Table 7 calculated peak discharge and bridge span

| River name and location | Peak Discharge (m3/s) | Bridge length (m) | Floodplain width(m) |
|---|---|---|---|
| Wogida River located Yirgachefe town | 131 | 15 | 323 |
| Yirgachefe River at Yirgachefe | 102 | 14 | 289 |

As shown in table 7 above of two bridges with a separate flood events were modeled and analyzed using HEC-RAS. After all data was inputted, several important parameters were varied in order to determine an optimum selection for each parameter. A water surface elevation profile was computed for each flood event. A profile simply consists of a computed water surface elevation at each cross-section. Computed elevations are then connected by a straight line as depicted in Figure 11 blow.

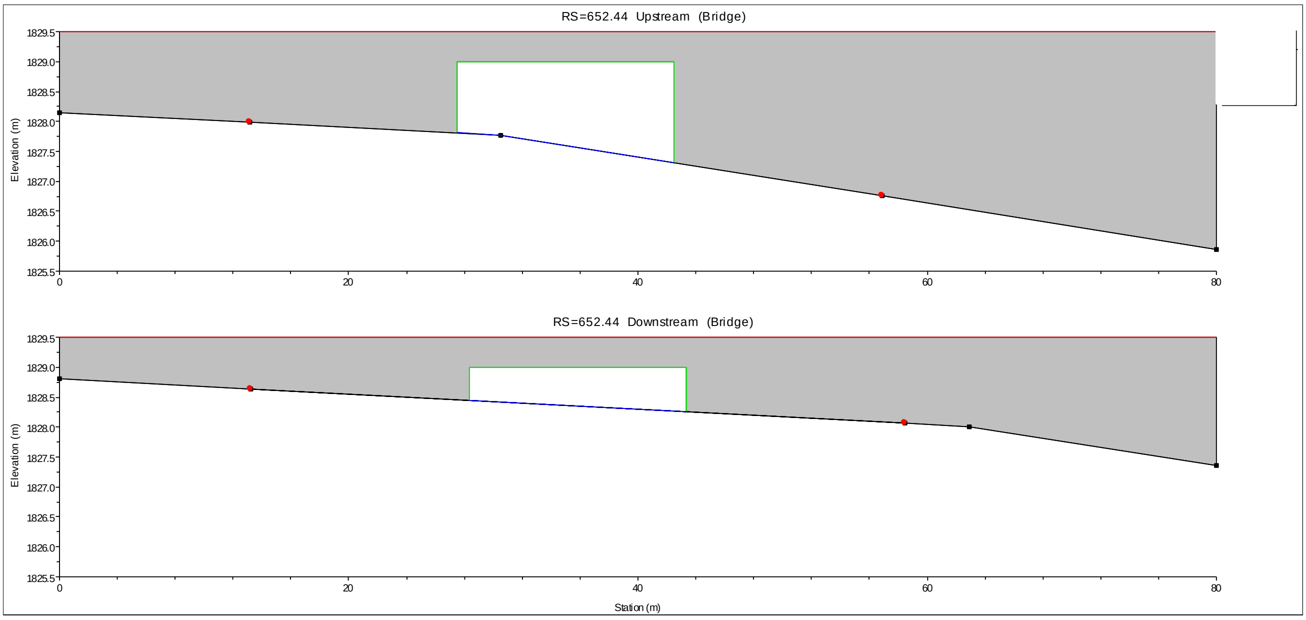


**Figure 11 water surface and bridge profile at Yirgachefe river.**

### 4.3.1 Bridge scouring

The most common cause of bridge failure is due to bridge scour of the foundation from stream beds and stream banks caused by moving water likewise at. Yirgachefe bridge scouring is cause of rapid movement of stream. Velocity of the flow just upstream of the abutment very high as indicated in result. Removal of material from bed and banks across most of the channel width. Bed material is already being transported into the contracted bridge section from upstream of the approach section.

At this bridge (Yirgachfe) analysis shows no construction scouring but abutment scouring is very high with total souring depth 0.82m the left bank of the river and 0.58m along the channel

Table 8 Hydraulic design and bridge scouring analysis result

| Hydraulic Design | | | | |
|---|---|---|---|---|
| Contraction Scour | | | | |
| Input Data | | Left bank | Channel | Right bank |
| | Average Depth (m): | | 1.74 | 2.22 |
| | Approach Velocity (m/s): | | 0.18 | 0.21 |
| | Br Average Depth (m): | | 1.65 | |
| | BR Opening Flow (m3/s): | | 23 | |
| | BR Top WD (m): | | 20 | |
| | Grain Size D50 (mm): | 2.2 | 4 | 2.2 |
| | Approach Flow ($m^3$/s): | | 9.47 | 13.53 |
| | Approach Top WD (m): | | 29.65 | 29.43 |
| | K1 Coefficient: | | 0.59 | 0.59 |
| Results | | | | |
| | Scour Depth Ys (m): | | 0 | |
| | Critical Velocity (m/s): | | 1.08 | |
| | Equation: | | Clear | |
| Abutment Scour | | | | |
| | | Left | Right | |
| Input Data | | | | |
| | Station at Toe (m): | 36.42 | 51.42 | |
| | Toe Sta at appr (m): | 35.68 | 52.82 | |
| | Abutment Length (m): | 7.04 | 36.47 | |
| | Depth at Toe (m): | 1.68 | 1.6 | |
| | K1 Shape Coef: | 1.00 - Vertical abutment | | |
| | Degree of Skew (degrees): | 90 | 90 | |
| | K2 Skew Coef: | 1 | 1 | |
| | Projected Length L' (m): | 7.04 | 36.47 | |
| | Avg Depth Obstructed Ya (m): | 1.74 | 2.12 | |
| | Flow Obstructed Qe ($m^3$/s): | 2.25 | 15.78 | |
| | Area Obstructed Ae (m2): | 12.23 | 77.47 | |
| Results | | | | |
| | Scour Depth Ys (m): | 0.82 | 0.58 | |

| | | | | |
|---|---|---|---|---|
| | Qe/Ae = Ve: | 0.18 | 0.2 | |
| | Froude #: | 0.04 | 0.04 | |
| | Equation: | Froehlich | Froehlich | |

Estimation of Design Floods at Yirgachefe Bridges

River Name = Wogida (south Region gedeo zone)

Eastings (UTM) = 411744, Nothings (UTM) = 679883

Catchment area (hec) = 13690

Design Flood (m3/s) 50 year = 112, 100 year = 175

Estimation of Hydraulics parameters

Manning coefficient of the existing bridges is determined based on filed survey of the natural channels of the rivers and the longitudinal slopes of the rivers from topographic survey. The parameters of the river channels of the bridges are given below:

Channel slope = 0.016

Manning's Coefficient = 0.03

Bridge Size Determination

The Bridge opening data (i.e. bridge total span, no piers and other bridge parameters) obtained from the structural survey and piers coefficients were estimated:

Bridge span = 15m , Height = 3.5m , Low cord Elevation = 1829m and High cord Elevation = 1839.52m

Different cross section intervals were recommended for the bridge, and for suitability 20m is used in this thesis, which may vary according to the suitability of the river section survey data. The layout of the x-sections and profile along the river is worked out for the bridge as shown below.

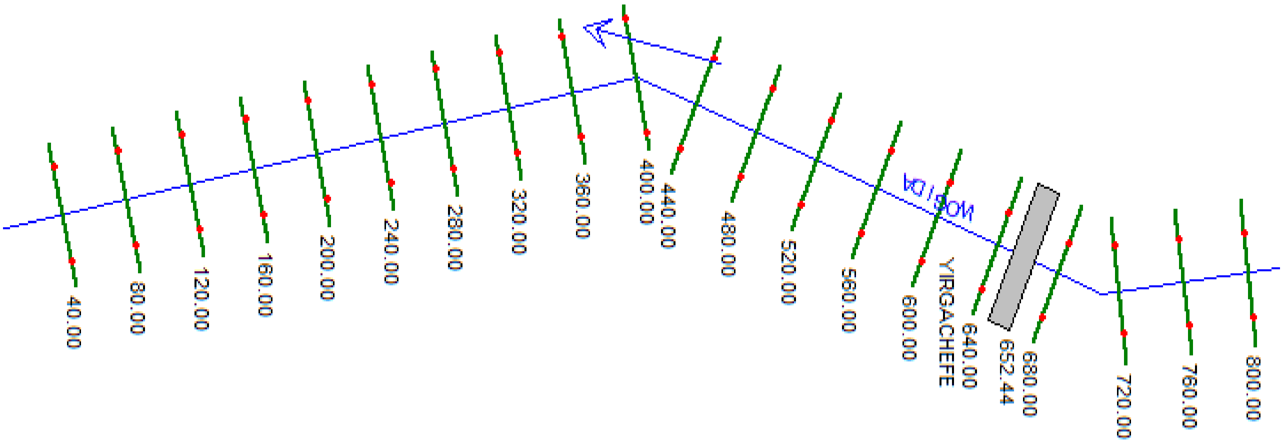


Figure 12 layout of X-section for hydraulic analysis of bridge

## 4.4 Site observation and inventory discussion

### 4.4.1culverts

Provision of pipe culverts at specified interval preferred to be economical, easy to construction and fulfills the minimum height of fill recommended. However, when the cross fall of ground is less than 0.5%, silting up of pipe culvert will occur. In this regard, provision of pipe culvert at cross fall >0.5% shall be considered to be economical and all these culvert are prefabricated from c35 reinforced concrete, compressive cube strength of 35mpa, and reinforced bar of Ø6 and Ø8 with the tensile strength of 300mpa. Casting and curing to attain the required quality of culvert, the list of pipe culvert along the whole road (see appendix A table 10)

### 4.4.2 Ditch

Since the project traverses through high cut section flow from this from this section has to be collected and drainage out to the nearest culvert for safe conveyance of water. For that manner a concrete U-ditched is provided in section considering its hydrologic/hydraulic requirement and easy construction. In addition to this trapezoidal pitched ditches are provided at some fill section.

## 4.5 Conditions of the existing drainage infrastructure.

### 4.5.1 Observed damage on minor structure

Site information was recorded for all of the existing structures on Yirgachefe-Hageremariam road upgrading project. The major comprises details of structure type, construction material, clearances, height of substructure etc. the entire common defect encounter.

Generally the following defects are observed on culverts.

- There is vegetation around inlet and outlet
- Blocking of inlet due to boulder
- High deposition of silt

- Deterioration of concrete
- Formation of water pond due to absence of sufficient slope
- Cracking of wing wall
- There is scouring problem
- Road position of the culvert
- And total blocked inlet and outlet condition due to silt up problem.

For the sake of demonstration of the above mentioned damages the following photographs were taken during site visit.


**Figure 13  Total blocked inlet condition at station 162+420 and at station 164+020**

## 4.6 Hydraulic analysis

### 4.6.1 Road Surface Drainage Structures

As it was observed, there are one bridges and one hundred seventy five (175) pipe culverts and fifteen (15) box culvert for road crossing drainage structure in the Hageremariam to Yirgachefe road. There are many drainage manholes for the surface drainage system along the newly constructed road , these manholes provide proper connection at the junctions of drainage ditches for regulating the water flow in the drainage structure. About 18134 meters (18.134km) of side concrete rectangular drain ditch were constructed on both sides of the roads and 3756m (3.756km) pitched trapezoidal ditch constructed at were slope is greater than 5% .

Total the road cover 72km, from this one can infer that only about 30.4 % of the road provided with defined side drain drainage structure masonry trapezoidal and rectangular types of side drain ditch were provided along the roads. From the constructed side ditches of town section, only about 23 % provided with cover protect the ditches from any intrusions or garbage.


Figure 14 Drainage structure scoring, erosion of soil and accumulation of silt

### 4.6.2 Road Surface Damage

Different types of damages to the roads in the Hageremariam to Yirgachefe were observed during the study. These are potholes, washing and deformations of the road pavements. Side slope of the road were cut down to the drainage and close the drainage ditches special high cut area. Deformation was observed on Hageremariam to Yirgachefe road around Fisahagenet area.

There is no regular maintenance of road and drainage structures as it was investigated during the study. Most of the side drain ditch is full of garbage and sediment at many places which obstruct the normal flow of water in the channel. Some drain ditches are also covered totally with grasses and shrubs and thus not giving the desired function for which it was constructed.

### 4.6.3 Runoff Water and Hydraulic Capacity

In this study, the runoff water generated from the drainage basin and passes through culvert have different opening size was determined based on ERA 2013 drainage design manual. The hydraulic capacities of the open channels in the study area were determined using the Manning's equation and WMS10.1 software. Accordingly, the peak rate of runoff and hydraulic capacities of the channel constructed were computed by the formulae stated and the obtained result presented in software output APPENDIX D culvert analysis report.

As it can be seen from output result most of the channels, are sufficient to carry the runoff water contributed to them with regard to their hydraulic property but at different number of station cannot carried out full discharge so that overtopping are occurred special during rainy season.

### 4.6.3. Road and Drainage Network Integration

As it was observed during the field investigation of the study, proper connections were made along the newly constructed asphalt road in which the curbstone properly constructed and inlet spacing was provided every 2m to 3m interval. In addition drainage manholes were constructed at required locations along this road. However on the rest of the roads proper connections were not provided. At some station non-uniform curbstone was provided with no inlet or opening to dispose water from road to the side ditch. In the junction of pipe culvert was provided and this create an obstruction to convey the water along the ditch and thus over flooding of water occurs at road crossing junction after every rainfall event. Figure 16 below shows flooding due to improper connections or integrations at this location. According to field observation made, some of the side drain ditches were constructed for nothing as there is no inlet or opening to collect storm water from the adjacent surrounding area or road. In some cases, the inverted levels of the ditches are above the elevation of the adjacent surrounding area and thus water cannot enter to the ditch. Rather, runoff water accumulated on the road damaging the pavement.

### 4.6.4 Flooding Problems

The result of the study shows that though the drainage problem is common in the area, the hazard of the flooding problem is dominant for about 28.6 % of the area and this flooded prone area is located at both upstream and downstream reach of the Gedeb town sub-catchment along the road. Two culvert over flooded with runoff water in July 2017 due to blockage by debris and the flooding extended to the surrounding residential buildings causing damages or loss to their property. In 2017 rainy season, over flooding of runoff water also occurred to the culvert in a rain season. Generally, linear type of storm water drainage U-ditch constructed in the study area of town section. But it was observed that liquid wastes released to the storm water drainage ditch andstreams from some residential buildings which affected the proper functioning of the drainage structures.


Figure 15 Rain season defects of drainage structures at *Gedeb* town (source field survey).

### 4.7 Culvert hydraulic

Road way overtopping will begin when the headwater, rises to the elevation of the roadway (table below). The overtopping will usually occur at the low point of a sag vertical curve on the roadway. From the recurrence analysis of Yirgachefe, culvert will begin overtopped at every after two years. Table blow shows us total discharge available for the culvert in given year and yirgachefe culvert can carry limited amount of discharge this problem leads the flow to overtop on roadway after two up to five years recursive period.

The total flow across the roadway then equals the sum of the roadway overflow plus the culvert flow. A trial and error procedure is necessary to separate the amount of water passing through the culvert, if any, from the amount overtopping the roadway.

Table 9 Summary of Culvert Flows at Yirgachefe Crossing

| Headwater Elevation (m) | Discharge Names | Total Discharge (cms) | yirgachefe Discharge (cms) | Roadway Discharge (cms) | Iterations |
|---|---|---|---|---|---|
| 1898.46 | 2 year | 1.2 5 | 1.25 | 0.00 | 1 |
| 1898.67 | 5 year | 2.10 | 1.50 | 0.60 | 4 |
| 1898.83 | 10 year | 3.27 | 1.66 | 1.61 | 4 |
| 1898.95 | 25 year | 4.35 | 1.77 | 2.57 | 4 |
| 1899.06 | 50 year | 5.39 | 1.86 | 3.53 | 4 |
| 1898.50 | Overtopping | 1.30 | 1.30 | 0.00 | Overtopping |

In some cases, culverts may be laid horizontal or on an adverse slope where the downstream elevation is higher than the upstream elevation. The tail water at a culvert is the depth of water at the downstream end of the culvert, as measured from the downstream invert of the culvert.

While water surface profiles are influenced by the channel slope, flow profiles are also classified by the water surface slope. When the flow is uniform and steady these slopes are the same. Since critical and normal depths vary with flow, the slope classification is a function of change slopes classifications between mild, steep and critical slopes as stream flows change.

Table 10 Culvert Summary Table: Yirgachefe

| Discharge Names | Total Discharge (cms) | Culvert Discharge (cms) | Headwater Elevation (m) | Inlet Control Depth (m) | Outlet Control Depth (m) | Normal Depth (m) | Critical Depth (m) | Outlet Depth (m) | Tailwater Depth (m) | Outlet Velocity (m/s) | Tailwater Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 year | 1.25 | 1.25 | 1898.46 | 1.100 | 0.679 | 0.398 | 0.661 | 0.476 | 0.190 | 3.547 | 3.290 |
| 5 year | 2.10 | 1.50 | 1898.67 | 1.314 | 0.984 | 0.443 | 0.722 | 0.532 | 0.266 | 3.714 | 3.953 |
| 10 year | 3.27 | 1.66 | 1898.83 | 1.473 | 1.116 | 0.470 | 0.755 | 0.566 | 0.356 | 3.821 | 4.587 |
| 25 year | 4.35 | 1.77 | 1898.95 | 1.595 | 1.214 | 0.490 | 0.776 | 0.589 | 0.432 | 3.897 | 5.029 |
| 50 year | 5.39 | 1.86 | 1899.06 | 1.702 | 1.291 | 0.506 | 0.791 | 0.607 | 0.501 | 3.962 | 5.381 |

## 4.8 Rainfall intensity duration frequency curve development

The probability distribution method is carried out to determine the rainfall and their corresponding return period. Now various short duration rainfalls like 5, 10, 15, 30, 60 and 120 min were estimated from this evaluated rainfall intensity for different return periods.

Table 11 Rainfall intensity study area

| Duration | Return period (T) year | | | | | |
|---|---|---|---|---|---|---|
| | 2-yr | 5-yr | 10-yr | 25-yr | 50-yr | 100-yr |
| 5-min | 99.932 | 122.354 | 138.469 | 161.746 | 179.909 | 197.907 |
| 10-min | 83.251 | 103.53 | 117.912 | 138.552 | 154.629 | 170.584 |
| 15-min | 71.418 | 89.914 | 102.916 | 121.487 | 135.933 | 150.284 |
| 20-min | 62.579 | 79.589 | 91.468 | 108.372 | 121.51 | 134.569 |
| 25-min | 55.72 | 71.477 | 82.426 | 97.96 | 110.024 | 122.019 |
| 30-min | 50.24 | 64.928 | 75.095 | 89.481 | 100.646 | 111.75 |
| 35-min | 45.759 | 59.526 | 69.024 | 82.434 | 92.836 | 103.181 |
| 40-min | 42.026 | 54.99 | 63.909 | 76.479 | 86.223 | 95.916 |
| 45-min | 38.866 | 51.124 | 59.538 | 71.376 | 80.548 | 89.672 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 50-min | 36.157 | 47.789 | 55.758 | 66.951 | 75.621 | 84.244 |
| 55-min | 33.807 | 44.881 | 52.454 | 63.076 | 71.3 | 79.479 |
| 60-min | 31.75 | 42.322 | 49.54 | 59.652 | 67.478 | 75.26 |
| 65-min | 29.933 | 40.051 | 46.95 | 56.603 | 64.071 | 71.497 |
| 70-min | 28.317 | 38.023 | 44.632 | 53.87 | 61.014 | 68.118 |
| 75-min | 26.87 | 36.199 | 42.544 | 51.405 | 58.255 | 65.065 |
| 80-min | 25.566 | 34.55 | 40.654 | 49.17 | 55.752 | 62.294 |
| 85-min | 24.386 | 33.051 | 38.934 | 47.133 | 53.469 | 59.765 |
| 90-min | 23.311 | 31.683 | 37.361 | 45.269 | 51.378 | 57.449 |
| 95-min | 22.329 | 30.429 | 35.918 | 43.557 | 49.456 | 55.317 |
| 100-min | 21.429 | 29.275 | 34.588 | 41.977 | 47.682 | 53.35 |
| 105-min | 20.599 | 28.209 | 33.359 | 40.516 | 46.04 | 51.527 |
| 110-min | 19.833 | 27.222 | 32.219 | 39.159 | 44.515 | 49.834 |
| 115-min | 19.122 | 26.304 | 31.159 | 37.896 | 43.095 | 48.257 |
| 120-min | 18.462 | 25.45 | 30.17 | 36.718 | 41.769 | 46.784 |

By using the rainfall intensity of above table for various durations, intensity duration frequency curve is plotted for various return periods. Figure 19 shows intensity duration frequency curve on semi log paper. The plot is curvature and intensity value decreases as duration increases. For particular duration as return period increases rainfall intensity tends to increases.

Table 12 Gumbel's distribution IDF equation coefficient value

| equation coefficient | $initensty = \frac{A}{(t_d+B)^C}$ (mm/hr) | | | | | |
|---|---|---|---|---|---|---|
| | 2-yr | 5-yr | 10-yr | 25-yr | 50-yr | 100-yr |
| A | 2080.035 | 2237.291 | 2430.049 | 2768.714 | 3052.429 | 3353.483 |
| B | 18.8 | 19.7 | 20.2 | 20.8 | 21.2 | 21.6001 |
| C | 0.9577 | 0.9062 | 0.8879 | 0.8738 | 0.8669 | 0.8628 |

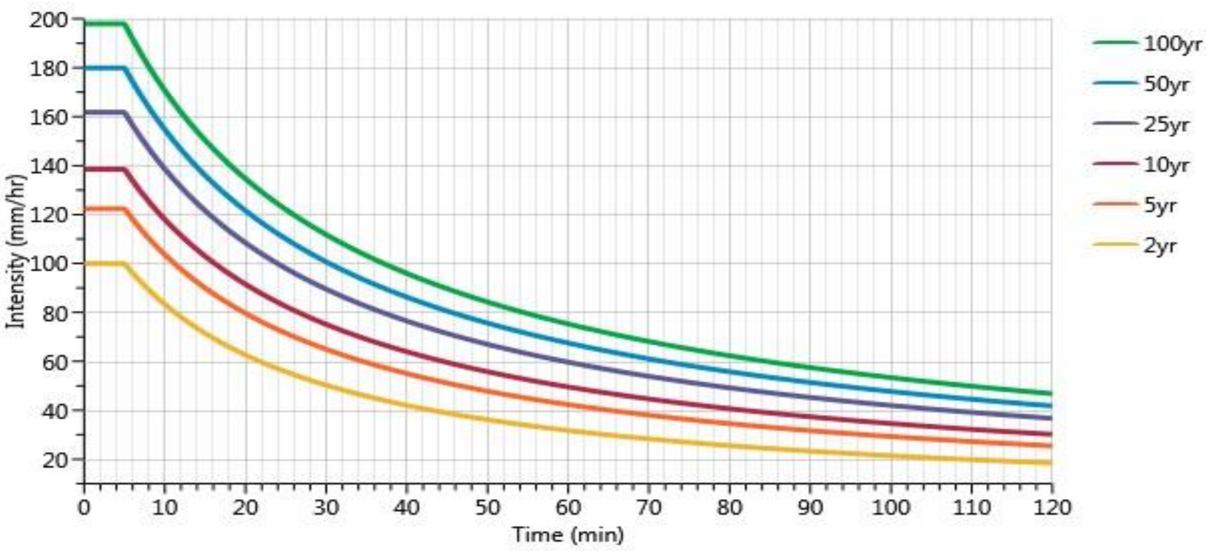


Figure 16 Intensity duration frequency plot

## Chapter five

## Conclusion and Recommendation

### 5.1 Conclusion

The hydraulic analysis of drainage structures on Yirgachefe-Hageremariam road was investigated through critical site observations. The capacity and adequacy of drainage system were investigated through hydrological analysis, site observation and questionnaires analysis. Under hydrologic analysis, return periods, IDF curves, 24-hour rainfall analysis, delineation of watershed area, computation of catchment parameters, and peak discharge computation were carried out. Under the questionnaires analysis was used to investigate by preparing the questionnaires for engineers, road users and residents based on the design capacity of the road, causes and effects of existing poor drainage system of the road.

The result of the study shows that though the drainage problem is common in the area, the hazard of the flooding problem is dominant for about 28.6 % of the area and this flooded prone area is located at downstream reach along the road. 10.5% of pipe culverts over flooded with runoff water in April, June and July 2017 due to blockage by debris and the flooding extended to the surrounding residential buildings causing damages or loss to their property. In 2018 rainy season, over flooding of runoff water also occurred to the Gedeb town three times in a season.

Generally it can be concluded that road surface drainage of the *Hageremariam* to *Yirgachefe* found to be inadequate due to insufficient drainage structures provision, Community of the residents thought that damping wastes in to the natural water ways and storm water drainage system and lack of proper interconnection between the road and drainage infrastructures thereby resulting damages to road surfacing material and flooding problems in the area.

- Inadequate integration between road and urban storm water drainage lines followed by blockage of drains by solid wastes and silt accumulation are the major causes of flooding in the study area.

Generally, separate type of storm water drainage ditch constructed in the study area. But it was observed that liquid wastes released to the storm water drainage ditch and streams from some residential buildings which affected the proper functioning of the drainage structures and creating environmental pollution.

The sides of the embankment also eroded at different section along the road by the high driving force of the surface runoff water contributed from the surrounding upstream reach of steeply are.

## 5.2 Recommendation

On *Yirgachefe-Hageremariam* road drainage structures analysis structures underperformance have had serious negative impact on road, dwellers along the road and road user. In order to minimize these negative impacts, the following appropriate mitigation measures are recommended.

Currently, Ethiopia use IDF curves as standards for water management infrastructure design, operation and maintenance. The IDF curve in use today for design of conveyance systems has been adopted and revised in 2010 for different region based on data from hydrological agency. To quote:

Note: Rainfall data used in the preparation of IDF curve of ERA DDM have been collected from meteorological service agency meteorology stations. Since adequate rainfall data is not available for the direct determination of intensity frequency curves for Ethiopia. in the course of the preparation of this manual, they have been subjected to statistical techniques. The results indicate that the country can be divided into the A1, A2, A3, A4, B1, B2, C1,and D2 hydrological regions displaying similar rainfall patterns. The information is reviewed with the current available data up to 2010, and future data may indicate the need for a further refinement in both values and regional boundaries (ERA DDM 2013).

Despite being outdated and originally derived for inadequate data, the IDF curves used for design of conveyance systems are conservative. Therefore one of the recommendations of this report is for the area to undertake a study and ascertain if using above IDF curve (fig-17) is appropriate for either present (or future) conditions.

- Proper road geometry need to be maintained to provide required crown and proper side drain drainage structures need to be provided for roads without drainage structures.
- Developing the skill of hydraulic and hydrologic analysis software for planning, analysis and design of storm water runoff and drainage system in road and monitoring the infrastructures.
- The drainage analysis has determined that increases in runoff from the Project will be mitigated by the cleaning drainage line and pipe culvert.
- Proactive measures should be taken to reduce and manage flooding hazards (like clearing of drains before rain season begins).
- Retaining wall is needed at different station of the road to minimize side erosion of soil and to protect accumulation of silt in drainage line.
- Teaching the community to aware released liquid wastes to the storm water drainage ditch and streams from residential buildings is cause for flooding and pollution of the environmental and air.

- At station 126+450,  129+980, 162+640, 180+380 weakness of carriage way occurred and dwellers shift their home during rainy season  due to lack of drainage structures.
- Clear the vegetation around inlet and outlet.
- Clear the boulder from inlet, lines and outlet of pipe culver and box culvert.
- Remove the deposited silt along the drainage line.
- Plastering for the deterioration concrete and week joint of the pipe culvert, box culvert and drain ditch.
- Provide end wall structure where ever necessary

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**Appendix A** Documents inventory of study road

Table 13 list of the pipe culvert throughout the road

| S.No. | station | Constructed pipe culvert | | |
|---|---|---|---|---|
| | | discharge | diameter/size | No. of barren |
| | | $m^3/s$ | (m) | |
| 1 | 126+420 | | 0.9 | 1 |
| 2 | 126+462 | | 0.9 | 1 |
| 3 | 126+530 | | 0.9 | 1 |
| 4 | 127+000 | 6.47 | 1.06 | 2 |
| 5 | 128+559 | | 1.06 | 1 |
| 6 | 128+832 | | 0.9 | 1 |
| 7 | 130+674 | | 0.9 | 1 |
| 8 | 130+674 | | 0.9 | 1 |
| 9 | 131+074 | | 0.9 | 1 |
| 10 | 131+309 | | 0.9 | 1 |
| 11 | 131+852 | | 1.22 | 1 |
| 12 | 132+348 | | 0.9 | 2 |
| 13 | 133+139 | | 0.9 | 1 |
| 14 | 133+445 | | 0.9 | 1 |
| 15 | 133+244 | | 0.9 | 1 |
| 16 | 134+795 | | 0.9 | 1 |
| 17 | 134+795 | | 0.9 | 1 |
| 18 | 135+541 | | 1.22 | 1 |
| 19 | 135+541 | | 0.9 | 1 |
| 20 | 136+299 | | 0.9 | 1 |
| 21 | 136+576 | | 0.9 | 1 |
| 22 | 137+077 | | 1.22 | 1 |
| 23 | 137+294 | | 0.9 | 1 |
| 24 | 728 | | 0.9 | 1 |
| 25 | 137+988 | | 1.22 | 1 |
| 26 | 138+295 | | 0.9 | 1 |
| 27 | 138+550 | | 1.22 | 1 |
| 28 | 139+550 | | 0.9 | 1 |
| 29 | 140+115 | | 0.9 | 1 |
| 30 | 140+347 | 7.28 | 1.22 | 2 |
| 31 | 140+567 | | 0.9 | 1 |
| 32 | 140+813 | | 0.9 | 2 |
| 33 | 141+101 | | 0.9 | 1 |
| 34 | 141+209 | | 0.9 | 1 |
| 35 | 141+440 | | 0.9 | 1 |
| 36 | 141+622 | | 0.9 | 1 |
| 37 | 142+072 | | 0.9 | 1 |
| 38 | 142+331 | | 0.9 | 1 |
| 39 | 142+630 | | 0.9 | 1 |
| 40 | 142+908 | | 0.9 | 1 |
| 41 | 143+147 | | 0.9 | 1 |

| | | | | |
|---|---|---|---|---|
| 42 | 143+147 | | 0.9 | 1 |
| 43 | 143+740 | | 0.9 | 1 |
| 44 | 143+926 | | 1.22 | 1 |
| 45 | 144+471 | | 0.9 | 1 |
| 46 | 145+680 | | 1.06 | 1 |
| 47 | 145+680 | | 0.9 | 1 |
| 48 | 146+735 | | 1.22 | 1 |
| 49 | 147+377 | | 0.9 | 1 |
| 50 | 147+774 | | 0.9 | 1 |
| 51 | 148+077 | | 0.9 | 1 |
| 52 | 148+331 | | 0.9 | 1 |
| 53 | 149+682 | | 1.22 | 1 |
| 54 | 150+533 | | 1.06 | 1 |
| 55 | 150+898 | | 0.9 | 1 |
| 56 | 151+638 | | 1.22 | 1 |
| 57 | 151+878 | 8.49 | 1.22 | 2 |
| 58 | 152+163 | | 0.9 | 1 |
| 59 | 152+310 | | 0.9 | 1 |
| 60 | 152+762 | | 0.9 | 1 |
| 61 | 153+506 | | 1.22 | 1 |
| 62 | 154+161 | | 0.9 | 1 |
| 63 | 154+734 | | 0.9 | 1 |
| 64 | 155+189 | | 0.9 | 1 |
| 65 | 156+532 | | 1.22 | 1 |
| 66 | 156+865 | | 1.06 | 1 |
| 67 | 157+202 | | 1.06 | 1 |
| 68 | 157+643 | | 0.9 | 1 |
| 69 | 158+022 | | 0.9 | 1 |
| 70 | 158+309 | | 0.9 | 1 |
| 71 | 158+727 | | 0.9 | 1 |
| 72 | 158+850 | | 0.9 | 1 |
| 73 | 159+410 | | 0.9 | 1 |
| 74 | 160+739 | | 0.9 | 1 |
| 75 | 161+200 | | 0.9 | 1 |
| 76 | 162+085 | | 1.22 | 1 |
| 77 | 162+697 | | 1.22 | 1 |
| 78 | 162+871 | | 1.22 | 1 |
| 79 | 163+796 | | 1.22 | 1 |
| 80 | 164+131 | | 0.9 | 1 |
| 81 | 164+359 | | 0.9 | 1 |
| 82 | 165+382 | | 0.9 | 1 |
| 83 | 165+755 | | 0.9 | 1 |
| 84 | 165+945 | | 0.9 | 1 |
| 85 | 166+231 | | 0.9 | 1 |
| 86 | 166+752 | | 0.9 | 1 |
| 87 | 167+256 | | 1.22 | 1 |
| 88 | 167+693 | | 1.22 | 1 |

| | | | | |
|---|---|---|---|---|
| 89 | 168+226 | | 0.9 | 1 |
| 90 | 168+545 | | 0.9 | 1 |
| 91 | 168+871 | | 0.9 | 1 |
| 92 | 169+425 | | 0.9 | 1 |
| 93 | 169+770 | | 0.9 | 1 |
| 94 | 170+128 | | 0.9 | 1 |
| 95 | 170+566 | | 0.9 | 1 |
| 96 | 170+975 | | 1.22 | 1 |
| 97 | 171+225 | | 1.22 | 1 |
| 98 | 171+368 | | 0.9 | 1 |
| 99 | 171+512 | | 0.9 | 1 |
| 100 | 171+828 | | 0.9 | 1 |
| 101 | 172+268 | | 0.9 | 1 |
| 102 | 172+456 | | 0.9 | 1 |
| 103 | 172+655 | | 0.9 | 1 |
| 104 | 172+836 | | 0.9 | 1 |
| 105 | 173+124 | | 0.9 | 1 |
| 106 | 173+480 | | 0.9 | 1 |
| 107 | 173+829 | | 0.9 | 1 |
| 108 | 174+476 | | 0.9 | 1 |
| 109 | 175+437 | | 0.9 | 1 |
| 110 | 176+755 | | 0.9 | 1 |
| 111 | 177+124 | | 1.22 | 1 |
| 112 | 177+568 | | 0.9 | 1 |
| 113 | 178+287 | | 0.9 | 1 |
| 114 | 178+628 | | 0.9 | 1 |
| 115 | 179+305 | | 0.9 | 1 |
| 116 | 179+673 | | 0.9 | 1 |
| 117 | 180+763 | | 0.9 | 1 |
| 118 | 182+495 | | 0.9 | 1 |
| 119 | 183+240 | | 0.9 | 1 |
| 120 | 183+572 | | 0.9 | 1 |
| 121 | 183+935 | | 0.9 | 1 |
| 122 | 184+730 | | 0.9 | 1 |
| 123 | 185+245 | | 0.9 | 1 |
| 124 | 185+351 | | 0.9 | 1 |
| 125 | 185+509 | | 0.9 | 1 |
| 126 | 185+780 | | 0.9 | 1 |
| 127 | 186+402 | | 0.9 | 1 |
| 128 | 186+802 | | 0.9 | 1 |
| 129 | 187+400 | | 0.9 | 1 |
| 130 | 187+867 | | 0.9 | 1 |
| 131 | 188+340 | | 0.9 | 1 |
| 132 | 189+185 | | 0.9 | 1 |
| 133 | 189+500 | | 0.9 | 1 |

**Table 14 pitched trapezoidal ditch throughout the project**

| S.No. | chainage | | Ditch length | Ditch type | Bottom width b | Side slope | Longitudinal slope | Depth including free bord | Ditch on road side |
|---|---|---|---|---|---|---|---|---|---|
| | m | | m | | m | H:1V | m/m | m | |
| 1 | 139+200 | 139+285 | 85 | Pitched Trapezoidal | 0.5 | 2 | 0.057 | 0.5 | L |
| 2 | 155+860 | 156+113 | 413 | Pitched Trapezoidal | 0.5 | 2 | 0.061 | 0.5 | L |
| 3 | 160+037 | 160+400 | 363 | Pitched Trapezoidal | 0.5 | 2 | 0.064 | 0.5 | R |
| 4 | 161+500 | 161+729 | 229 | Pitched Trapezoidal | 0.5 | 2 | 0.069 | 0.5 | R |
| 5 | 173+480 | 173+829 | 346 | Pitched Trapezoidal | 0.5 | 2 | 0.049 | 0.5 | R |
| 6 | 174+934 | 175+200 | 266 | Pitched Trapezoidal | 0.5 | 2 | 0.100 | 0.5 | R |
| 7 | 180+520 | 180+670 | 130 | Pitched Trapezoidal | 0.5 | 2 | 0.057 | 0.5 | R |
| 8 | 181+800 | 182+200 | 400 | Pitched Trapezoidal | 0.5 | 2 | 0.061 | 0.5 | L |
| 9 | 183+063 | 183+240 | 180 | Pitched Trapezoidal | 0.5 | 2 | 0.064 | 0.5 | L |
| 10 | 183+460 | 183+560 | 100 | Pitched Trapezoidal | 0.5 | 2 | 0.069 | 0.5 | L |
| 11 | 186+180 | 186+402 | 222 | Pitched Trapezoidal | 0.5 | 2 | 0.049 | 0.5 | R |
| 12 | 191+361 | 191+890 | 529 | Pitched Trapezoidal | 0.5 | 2 | 0.051 | 0.5 | R |
| 13 | 192+200 | 192+390 | 190 | Pitched Trapezoidal | 0.5 | 2 | 0.049 | 0.5 | L |
| 14 | 193+950 | 194+250 | 300 | Pitched Trapezoidal | 0.5 | 2 | 0.05 | 0.5 | L |

**Questionnaire**

This questionnaire is prepared for the collection of data to investigate in the study of the Hydraulic analysis of road drainage structures cause study on the Bule horato Yirgachefe Road. The information collected is confidential and will strictly be used for related data with the study.

Practical Aspect

1. Your academic background or field of training?
   A. Engineer
   B. Any other (specify) ……………………………………………………………………

2 What are some of the considerations that are made when coming up with road design and appropriate drainage facility in Bule horato Yirgachefe road?

A. State of road
B. Cost of construction
C. Class of the road
D. Period of construction
E. Topography

3 From your design experience, was the Drainage design appropriate?

A. Yes
B. No

4 Do you think the contractor observed due diligence in the construction of the road drainage systems?

A Yes

B No

If your answer above is yes, why do you think so? …………………………………………

5 At above Q#4 if your answer is no, in your opinion what percentage of roads in Ethiopia are not provided with adequate drainage system?

A. 0 – 20%
B. 20 – 40%
C. 40 – 60%
D. 60 – 80%
E. 80 – 100%

6 From your engineering experience and practice, how can you rate the state of the drainage system in Bule horato Yirgachefe road?

A. Excellent
B. Very good
C. Good

D. Poor
E. Any other (specify) ……………………………………………………………….

7 Have you carried out a research on the Hydraulic analysis of drainage system on the surrounding environment?

A Yes

B No

8 If yes, what did you find the causes and effects of poor drainage system on Asphalt road and their solution?

1. …………………………
2. …………………………
3. …………………………
4. …………………………

9 What do you think is the remedy to the solution state of the drainage system in Hageremariam to Yirgacefe road?

A. Maintenance
B. Redesigning
C. Reconstruction
D. Any other (specify) ……………………………………………………………………

10 Why do you think has hindered the above mentioned measures from being implemented?

A. Lack of resources
B. Lack of awareness
C. Poor planning
D. Lack of commitment by the government

11 Which of the following descriptions is the best suitable type of drainage system existing in Hageremariam to Yirgachefe road? More than one answer may be ticked.

A. Separate system
B. Combined system
C. Open channel drainage
D. Subsurface drainage
E. Any other (please specify) ------------------------------------------------------------------

12) In your opinion how do you find the condition of the drainage system in Hageremariam to Yirgachefe road?

A. Very good condition
B. Good condition
C. Fair condition
D. Poor condition
E.

13) How does poor drainage affect the road?

A. Runoff on the road block the road
B. Runoff washes away the asphalt
C. Cracking of road surface
D. Water leaves debris on the road surface
E. Any other (specify) -------------------------------------------------------

14) What are the main challenges faced by solving over flooding hazards in Hageremariam to Yirgachefe road?

A. …………………
B. …………………
C. …………………
D. ………………

15) How does poor drainage of the road affect you as the resident?

A. Runoff erodes the land
B. Runoff create valleys on your land
C. Runoff washes away yields
D. Runoff washes away asphalt road
E. Any other (specify)……………………………………………………………

16) Have you observed any improvements on the drainage system?

A. Yes
B. No

17) In your own view, how satisfied are you as a road user or resident with the state of drainage of the road?

A. Extremely satisfied
B. Satisfied
C. Dissatisfied
D. Extremely dissatisfied

18) What is your opinion on the responsibility of highway drainage system problems?

A. Strong responsibility
B. Faire responsibility
C. Limited responsibility
D. No responsibility

19) In your opinion, which of the following problem is the most serious that needs immediate Solution in road drainage system?

A. Lack of good drainage systems
B. high traffic accidents due to drainage
C. high soil erosions
D. Other (If any) ---------------------------------------------

20) How do you perform the assessment taken to solve the drainage problems?

A. Very good
B. God
C. Fair
D. Poor
E. Very poor

21) What are the major causes of drainage structures underperformance on Hagermariam-Yirgachefe road?

A. Poor design
B. Poor construction
C. Poor maintenance
D. Other (if any) ______________________________________________________

22) Are the hydraulic capacities of the different drainage elements of the road adequate?

A. Yes
B. NO

23) In your own opinion based on the professional experience, is the type of drainage facility installed in Hageremariam to Yirgachefe road has enough capacity to satisfactorily drain the water from the road?

A. Yes
B. No

If your answer above is no, why do you think so?

____________________________________________________________________

____________________________________________________________________

24) from your past design and construction experience what are the major challenges in drainage system.

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

____________________________________________________________________

25) If you have any related idea that not described in the above questions please, use space blow

**Table 15 Design Storm Frequency (Yrs) by Geometric Design Criteria**

| Structure Type | Geometric Design Standard | | | |
|---|---|---|---|---|
| | DS1/DS2 | DS3/DS4 | DS5/6/7 | DS8/9/10 |
| Gutters and Inlets* | 10/5 | 2 | 2 | - |
| Side Ditches | 10 | 10 | 5 | 5 |
| Ford/Low-Water Bridge | - | - | - | 5 |
| Culvert, pipe (see Note) Span<2m | 25 | 10 | 5 | 5 |
| Culvert, 2m<span <6m | 50 | 25 | 10 | 10 |
| Short Span Bridges 6m<span<15m | 50 | 50 | 25 | 25 |
| Medium Span Bridges 15m<span<50m | 100 | 50 | 50 | 50 |
| Long Span Bridges spans>50m | 100 | 100 | 100 | 100 |
| Check/Review Flood | 200 | 200 | 100 | 100 |

**Table 16 runoff curve number (Ethiopia Road Authority drainage design, 2013)**

| Land use | | | A | B | C | D |
|---|---|---|---|---|---|---|
| Cultivated land | Without conservation treatment | | 72 | 81 | 88 | 91 |
| | With conservation treatment | | 62 | 71 | 78 | 81 |
| Pasture land | Poor condition | | 68 | 79 | 86 | 89 |
| | Good condition | | 39 | 61 | 74 | 80 |
| Meadow | | | 30 | 58 | 71 | 78 |
| Wood or forest | Thin stand, poor cover, no mulch | | 45 | 66 | 77 | 83 |
| | Good cover | | 25 | 55 | 70 | 77 |
| Open spaces, lawns, parks | Good condition, grass cover >75% of area | | 39 | 61 | 74 | 80 |
| | Fair condition, grass on 50-75% | | 49 | 69 | 79 | 84 |
| Urban districts | Commercial and business areas, 85% impervious | | 89 | 92 | 94 | 95 |
| | Industrial districts, 70% impervious | | 81 | 88 | 91 | 93 |
| Residential | Average lot size | Average % impervious | | | | |
| | < 0.05 hectares | 65 | 77 | 85 | 90 | |
| | 0.1 hectares | 38 | 61 | 75 | 83 | |
| | 0.2 hectares | 25 | 54 | 70 | 80 | |
| | 0.4 hectares | 20 | 51 | 68 | 79 | |
| | 0.8 hectares | 12 | 46 | 65 | 77 | |
| Paved roads with curbs and storm drains, paved parking areas, roofs. | | | 98 | 98 | 98 | 98 |
| Gravel roads | | | 76 | 85 | 89 | 91 |
| Earth roads | | | 72 | 82 | 87 | 89 |
| Open water | | | 0 | 0 | 0 | 0 |

**Table 17 Antecedent Moisture Conditions (ERA DDM, 2013 for LVRs)**

| Regions(*) | Antecedent Moisture Conditions |
|---|---|
| D | Dry |
| B | Wet |
| All other regions | Average |
| Bahir Dar area | Although in region A, use wet |

Table 18 Conversion of CN from AAM conditions to dry and wet condition

| CN for average conditions | Corresponding CN's | |
|---|---|---|
| | Dry | Wet |
| 100 | 100 | 100 |
| 95 | 87 | 98 |
| 90 | 78 | 96 |
| 85 | 70 | 94 |
| 80 | 63 | 91 |
| 75 | 57 | 88 |
| 70 | 51 | 85 |
| 65 | 45 | 82 |
| 60 | 40 | 78 |
| 55 | 35 | 74 |
| 50 | 31 | 70 |
| 45 | 26 | 65 |
| 40 | 22 | 60 |
| 35 | 18 | 55 |
| 30 | 15 | 50 |
| 25 | 12 | 43 |
| 15 | 6 | 30 |
| 5 | 2 | 13 |

**Table 19 24 hour rainfall depth (mm) versus frequency (yrs).**

| Region | 24 HOUR DEPTH (mm) vs. FREQUENCY (yrs) TABLE | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 25 | 50 | 100 |
| A1, A4 | 60 | 79 | 93 | 113 | 127 | 142 |
| A2, A3 | 52 | 67 | 79 | 95 | 107 | 118 |
| B and C | 65 | 84 | 98 | 118 | 132 | 147 |
| D | 67 | 89 | 105 | 127 | 144 | 161 |
| Bahir Dar | 74 | 106 | 131 | 163 | 187 | 211 |

**Table 20 Initial abstracts ($I_a$) Values for Runoff Curve Numbers**

| Curve Number | $I_a$ (mm) | Curve Number | $I_a$ (mm) | Curve Number | $I_a$ (mm) |
|---|---|---|---|---|---|
| 40 | 76.2 | 60 | 33.9 | 80 | 12.7 |
| 41 | 73.1 | 61 | 32.5 | 81 | 11.9 |
| 42 | 70.2 | 62 | 31.1 | 82 | 11.2 |
| 43 | 67.3 | 63 | 29.8 | 83 | 10.4 |
| 44 | 64.6 | 64 | 28.6 | 84 | 9.7 |
| 45 | 62.1 | 65 | 27.4 | 85 | 9.0 |
| 46 | 59.6 | 66 | 26.2 | 86 | 8.3 |
| 47 | 57.3 | 67 | 25.0 | 87 | 7.6 |
| 48 | 55.0 | 68 | 23.9 | 88 | 6.9 |
| 49 | 52.9 | 69 | 22.8 | 89 | 6.3 |
| 50 | 50.8 | 70 | 21.8 | 90 | 5.6 |
| 51 | 48.8 | 71 | 20.6 | 91 | 5.0 |
| 52 | 46.9 | 72 | 19.8 | 92 | 4.4 |
| 53 | 45.1 | 73 | 18.8 | 93 | 3.8 |
| 54 | 43.3 | 74 | 17.9 | 94 | 3.3 |
| 55 | 41.6 | 75 | 16.9 | 95 | 2.7 |
| 56 | 39.9 | 76 | 16.1 | 96 | 2.1 |
| 57 | 38.3 | 77 | 15.2 | 97 | 1.6 |
| 58 | 36.8 | 78 | 14.3 | 98 | 1.0 |
| 59 | 35.3 | 79 | 13.5 | 99 | 0.4 |

**APPENDIX B GRAPH**

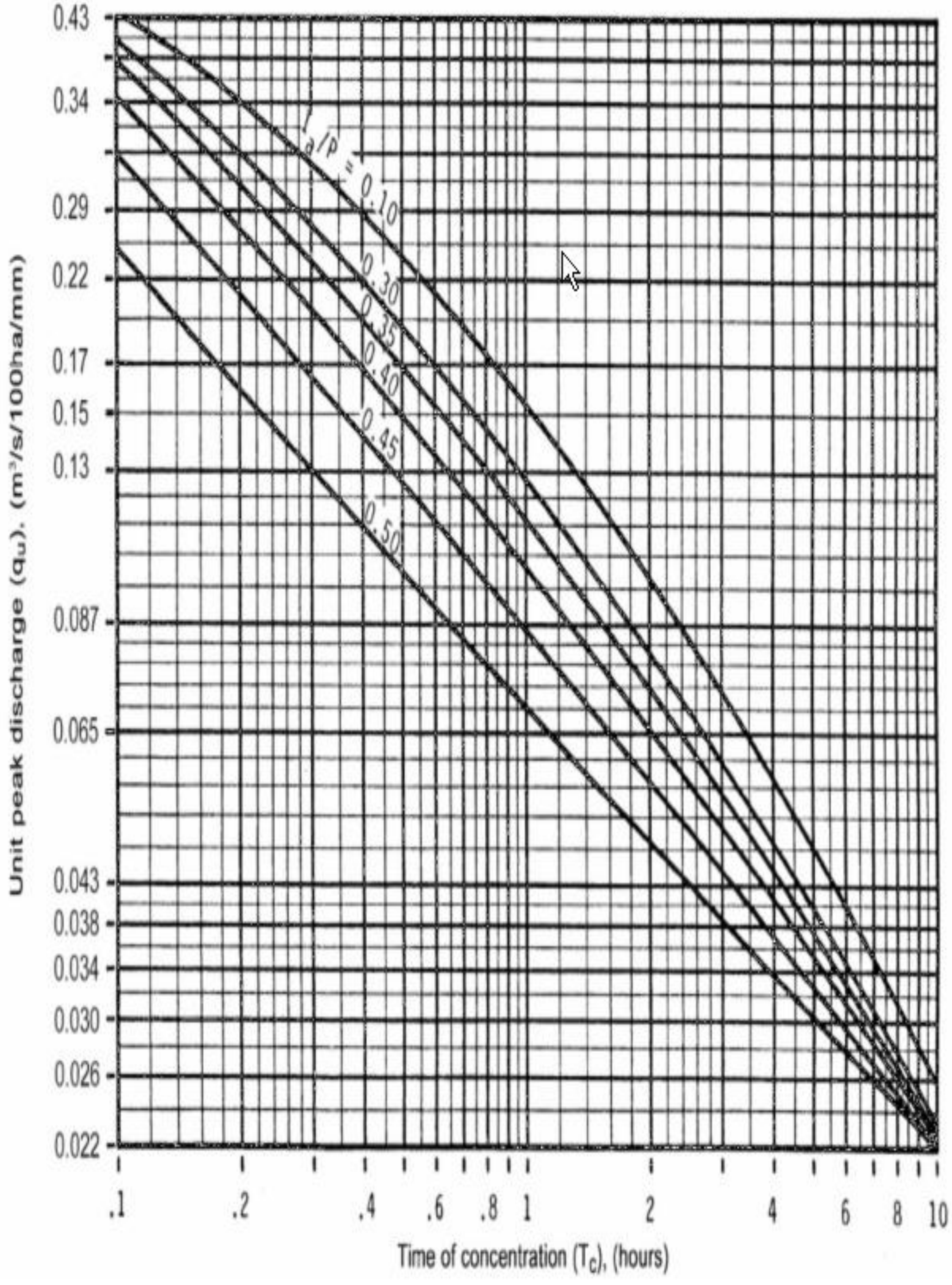



Figure 17 unit peak discharge type II Rainfall

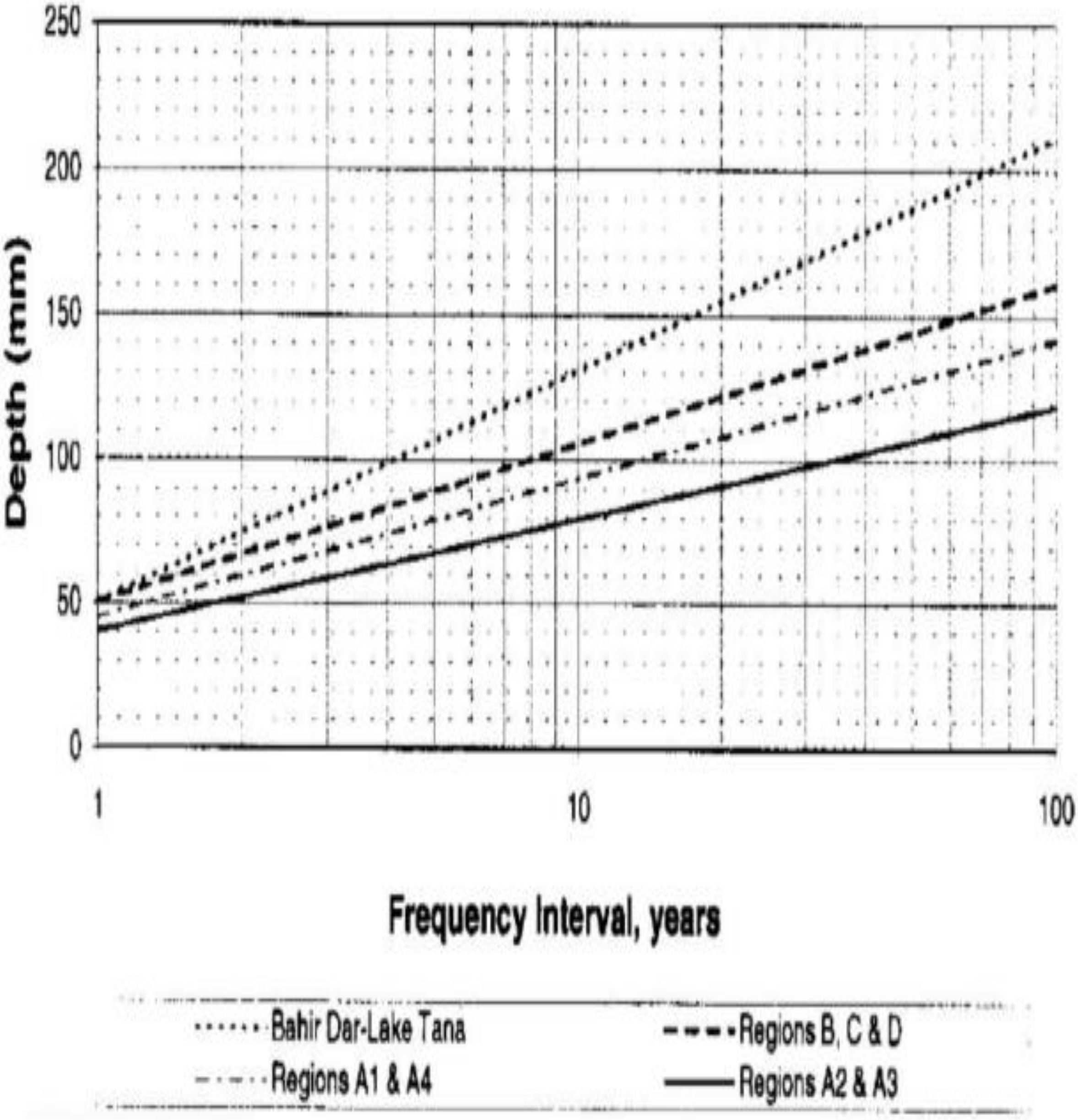



Figure 18 Hour Depth – Frequency curves

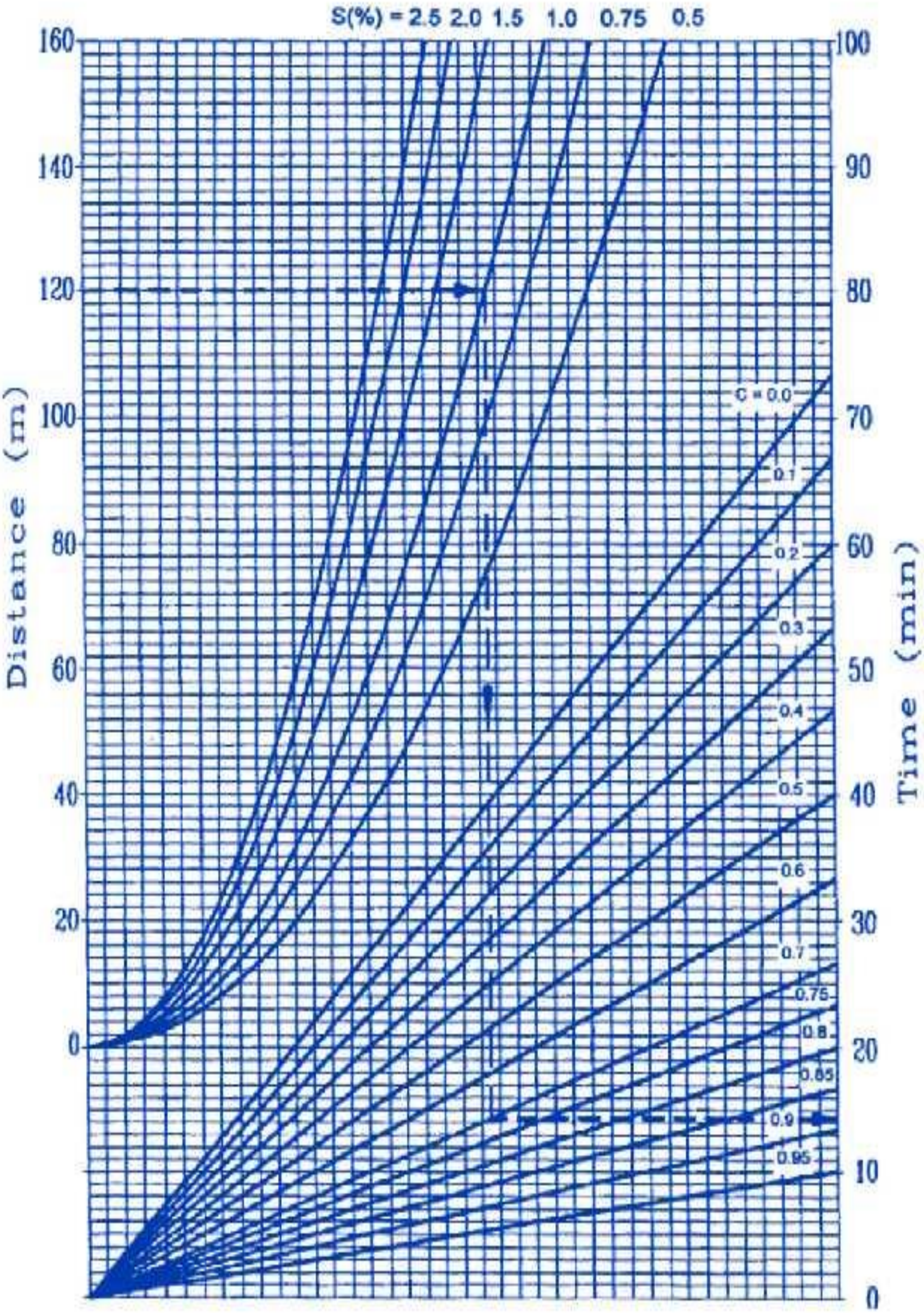



Figure 19 Overland Time of Flow

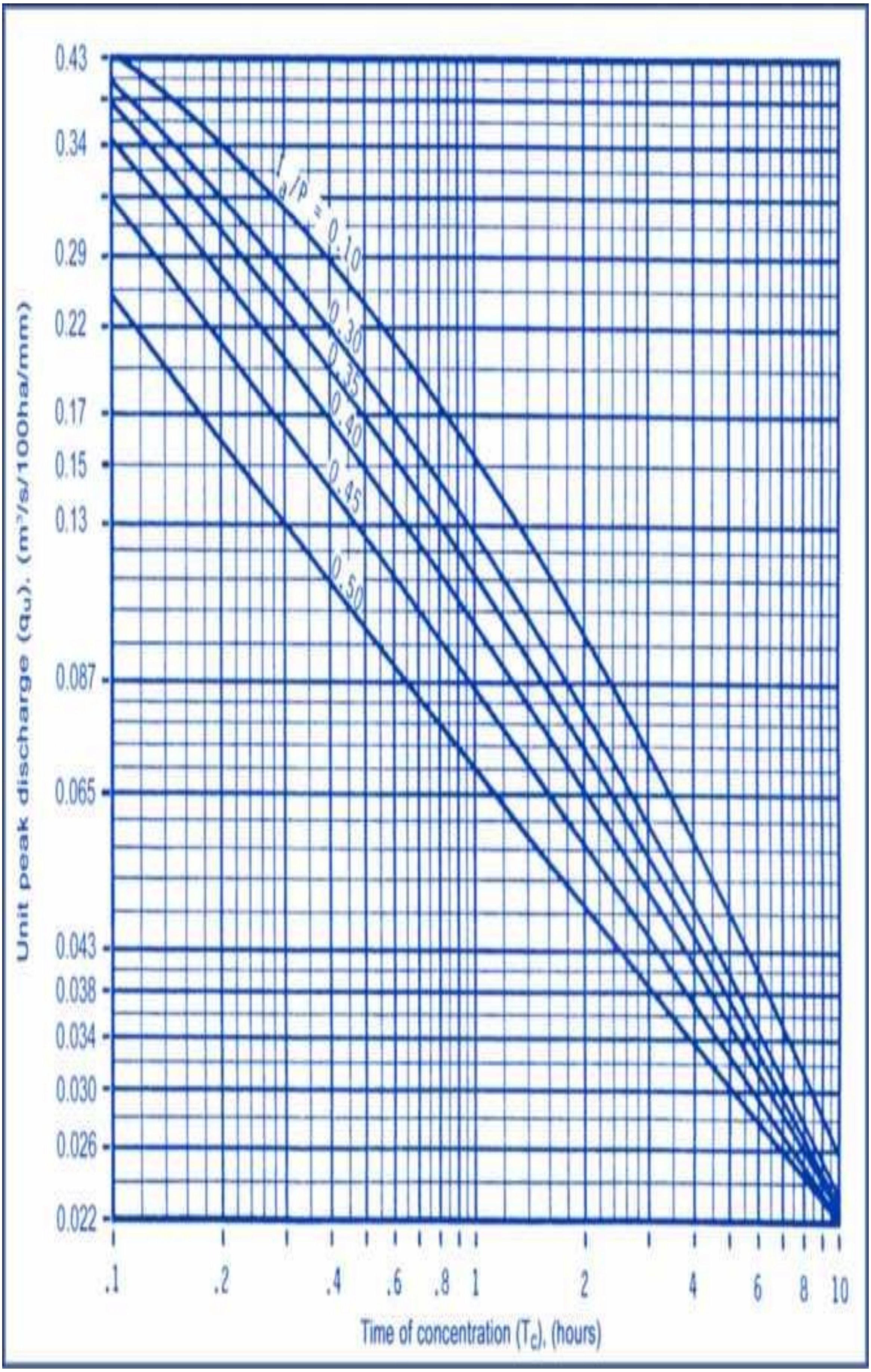



Figure 20 unit peak discharge

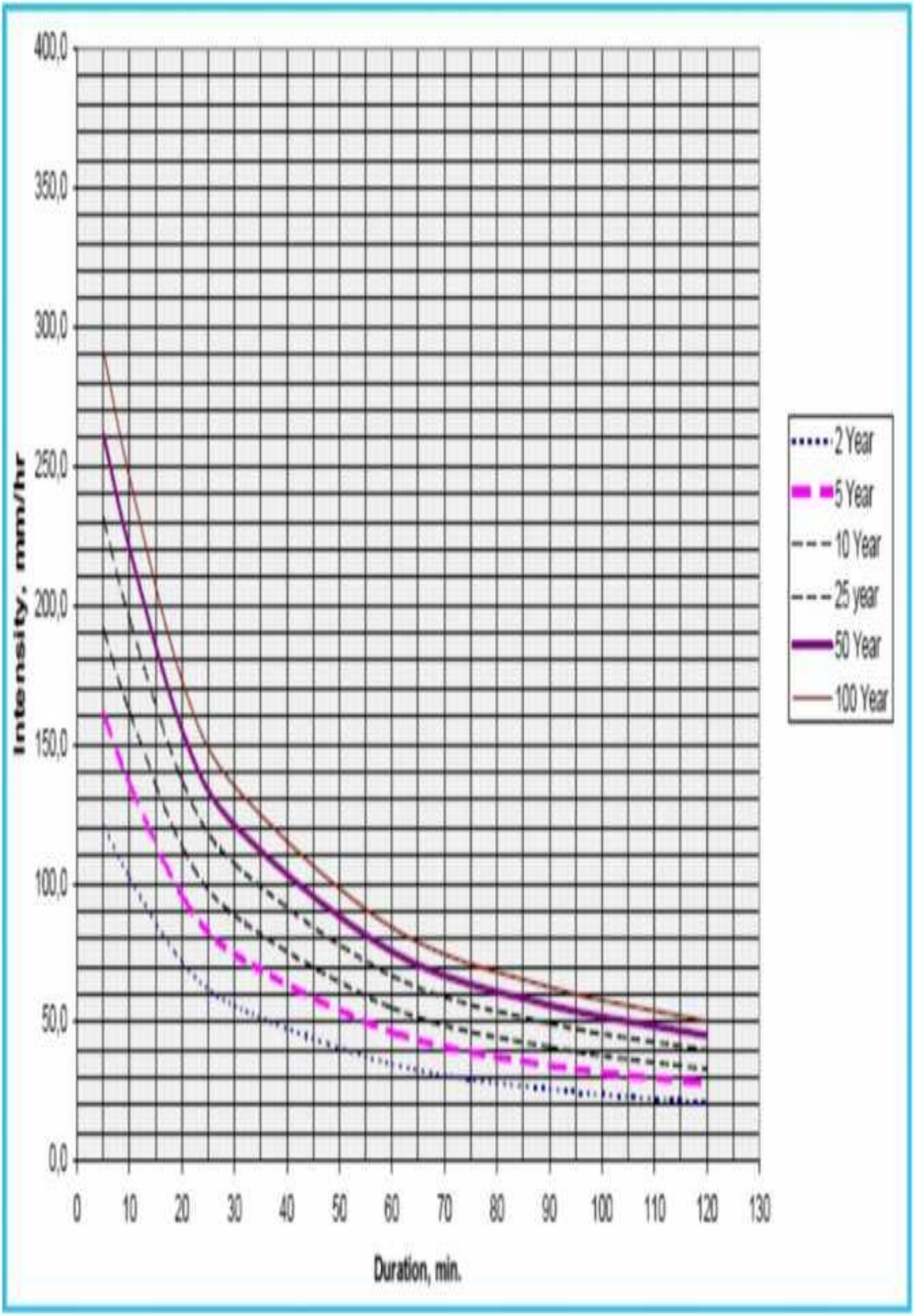



Figure 21 Intensity-Duration-Frequency Curve for Region B, C and D (ERA DDM, 2013)

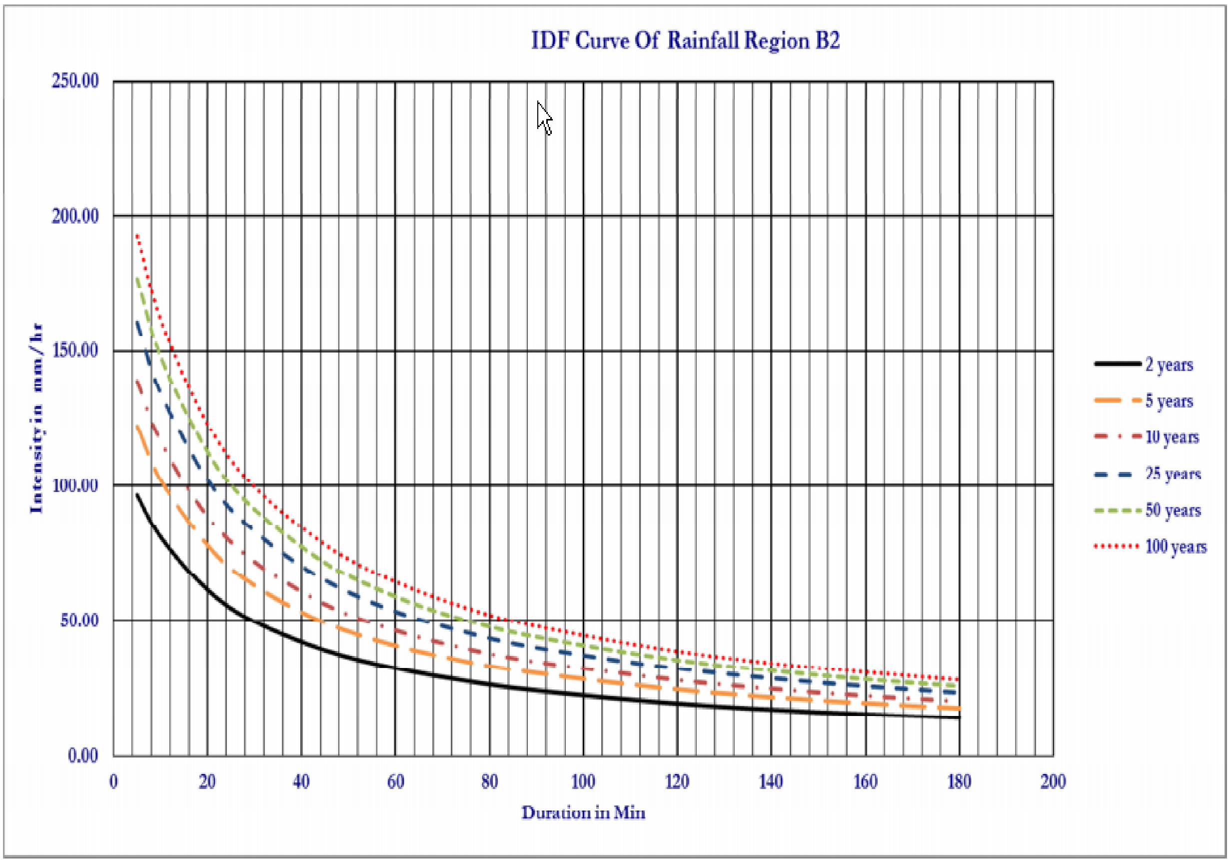



**Figure 22: IDF Curve of Rainfall Region B2**

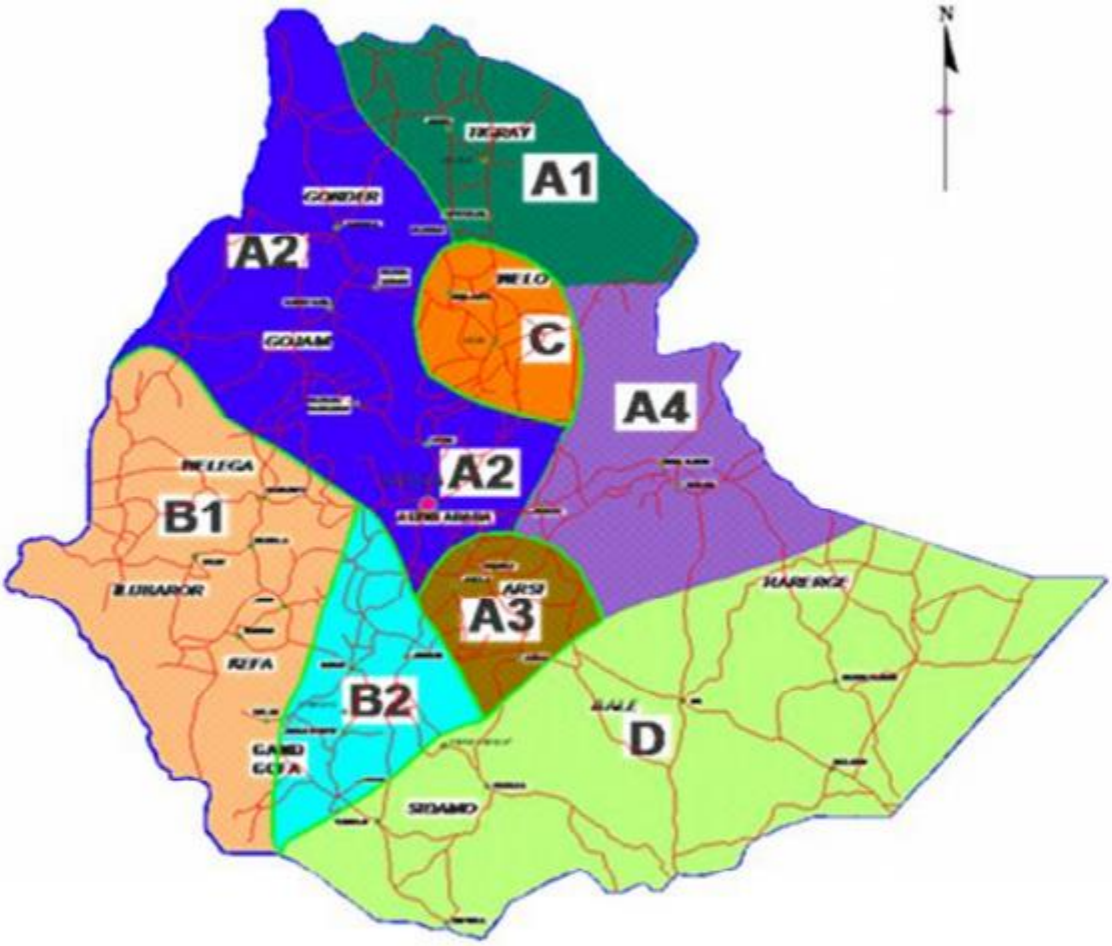



Figure 23 Rainfall Region of Ethiopia

## APPENIDIX C ROUGHNESS AND RUNOFF COEFFICIENT VALUE

**Table 21 Values of Roughness Coefficient (n) for Uniform Flow**

| Type of Channel and Description | Minimum | Normal | Maximum |
|---|---|---|---|
| **EXCAVATED OR DREDGED** | | | |
| a. Earth, straight and uniform | | | |
| 1. Clean, recently completed | 0.016 | 0.018 | 0.020 |
| 2. Clean, after weathering | 0.018 | 0.022 | 0.025 |
| 3. Gravel, uniform section, clean | 0.022 | 0.025 | 0.030 |
| 4. With short grass, few weeds | 0.022 | 0.027 | 0.033 |
| b. Earth, winding and sluggish | | | |
| 1. No vegetation | 0.023 | 0.025 | 0.030 |
| 2. Grass, some weeds | 0.025 | 0.030 | 0.033 |
| 3. Dense Weeds or aquatic plants in deep channels | 0.030 | 0.035 | 0.040 |
| 4. Earth bottom and rubble sides | 0.025 | 0.030 | 0.035 |
| 5. Stony bottom and weedy sides | 0.025 | 0.035 | 0.045 |
| 6. Cobble bottom and clean sides | 0.030 | 0.040 | 0.050 |
| c. Backhoe-excavated or dredged | | | |
| 1. No vegetation | 0.025 | 0.028 | 0.033 |
| 2. Light brush on banks | 0.035 | 0.050 | 0.060 |
| d. Rock cuts | | | |
| 1. Smooth and uniform | 0.025 | 0.035 | 0.040 |
| 2. Jagged and irregular | 0.035 | 0.040 | 0.050 |
| e. Channels not maintained, weeds and brush uncut | | | |
| 1. Dense weeds, high as flow depth | 0.050 | 0.080 | 0.120 |
| 2. Clean bottom, brush on sides | 0.040 | 0.050 | 0.080 |
| 3. Same, highest stage of flow | 0.045 | 0.070 | 0.110 |
| 4. Dense brush, high stage | 0.080 | 0.100 | 0.140 |
| **NATURAL STREAMS** | | | |
| 1 Minor streams (top width at flood stage < 30 m) | | | |
| a. Streams on Plain | | | |
| 1. Clean, straight, full stage, no rins or deep pools | 0.025 | 0.030 | 0.033 |
| 2. Same as above, but more stones and weeds | 0.030 | 0.035 | 0.040 |
| 3. Clean, winding, some pools and shoals | 0.033 | 0.040 | 0.045 |
| 4. Same as above, but some weeds and stones | 0.035 | 0.045 | 0.050 |
| 5. Same as above, lower stages, more ineffective slopes and sections | 0.040 | 0.048 | 0.055 |
| 6. Same as 4, but more stones | 0.045 | 0.050 | 0.060 |
| 7. Sluggish reaches, weedy, deep pools | 0.050 | 0.070 | 0.080 |
| 8 Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush | 0.075 | 0.100 | 0.150 |
| b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages | | | |
| 1. Bottom: gravel, cobbles, and few boulders | 0.030 | 0.040 | 0.050 |
| 2. Bottom: cobbles with large boulders | 0.040 | 0.050 | 0.070 |
| 2 Flood Plains | | | |
| a. Pasture, no brush | | | |
| 1. Short grass | 0.025 | 0.030 | 0.035 |
| 2. High grass | 0.030 | 0.035 | 0.050 |

| Type of Channel and Description | Minimum | Normal | Maximum |
|---|---|---|---|
| b. Cultivated area | | | |
| 1. No crop | 0.020 | 0.030 | 0.040 |
| 2. Mature row crops | 0.025 | 0.035 | 0.045 |
| 3. Mature field crops | 0.030 | 0.040 | 0.050 |
| c. Brush | | | |
| 1. Scattered brush, heavy weeds | 0.035 | 0.050 | 0.070 |
| 2. Light brush and trees in winter | 0.035 | 0.050 | 0.060 |
| 3. Light brush and trees, in summer | 0.040 | 0.060 | 0.080 |
| 4. Medium to dense brush, in winter | 0.045 | 0.070 | 0.110 |
| 5. Medium to dense brush, in summer | 0.070 | 0.100 | 0.160 |
| d. Trees | | | |
| 1. Dense willows, summer, straight | 0.110 | 0.150 | 0.200 |
| 2. Cleared land with tree stumps, no sprouts | 0.030 | 0.040 | 0.050 |
| 3. Same as above, but with heavy growth of spouts | 0.050 | 0.060 | 0.080 |
| 4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches | 0.080 | 0.100 | 0.120 |
| 5. Same as above, but with flood stage reaching branches | 0.100 | 0.120 | 0.160 |
| 3 Major Streams (top width at flood stage > 30 m). The n value is less than that for minor streams of similar description, because banks offer less effective resistance. | | | |
| a. Regular section with no boulders or brush | 0.025 | -- | 0.060 |
| b. Irregular and rough section | 0.035 | -- | 0.100 |
| 4 Various Open Channel Surfaces | | | |
| a. Concrete | 0.012- | 0.020 | |
| b. Gravel bottom with: | | | |
| Concrete | 0.020 | | |
| Mortared stone | 0.023 | | |
| Riprap | 0.033 | | |
| c. Natural Stream Channels | | | |
| Clean, straight stream | 0.030 | | |
| Clean, winding stream | 0.040 | | |
| Winding with weeds and pools | 0.050 | | |
| With heavy brush and timber | 0.100 | | |
| d. Flood Plains | | | |
| Pasture | 0.035 | | |
| Field Crops | 0.040 | | |
| Light Brush and Weeds | 0.050 | | |
| Dense Brush | 0.070 | | |
| Dense Trees | 0.100 | | |

**Table 22 Recommended Runoff Coefficient (C) for Various Selected Land Uses**

| Description of Area | | Runoff Coefficients |
|---|---|---|
| Business: Downtown areas | | 0.70-0.95 |
| Neighborhood areas | | 0.50-0.70 |
| Residential: | Single-family areas | 0.30-0.50 |
| | Multi units, detached | 0.40-0.60 |
| | Multi units, attached | 0.60-0.75 |
| | Suburban | 0.25-0.40 |
| Residential (0.5 hectare lots or more) | | 0.30-0.45 |
| Apartment dwelling areas | | 0.50-0.70 |
| Industrial: | Light areas | 0.50-0.80 |
| | Heavy areas | 0.60-0.90 |
| Parks, cemeteries | | 0.10-0.25 |
| Playgrounds | | 0.20-0.40 |
| Railroad yard areas | | 0.20-0.40 |
| Unimproved areas | | 0.10-0.30 |

Source: Hydrology, Federal Highway Administration, HEC No. 19, 1984

## APPENDIX D ANALYSIS RESULT AND SOFTWARE OUTPUT

HY-8 Culvert Analysis Report

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0 cfs

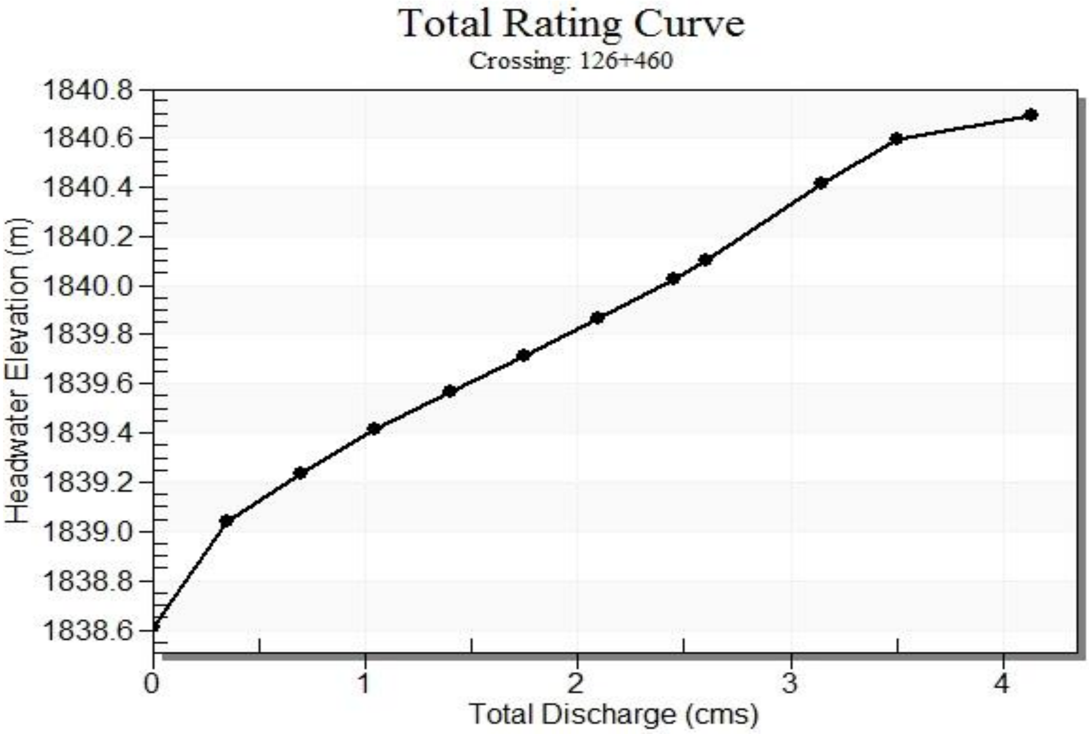
Design Flow: 91.8181 cfs

Maximum Flow: 123.601 cfs

**Table 23 - Summary of Culvert Flows at Crossing: 126+460**

| Headwater Elevation (m) | Total Discharge (cms) | Culvert 1 Discharge (cms) | Roadway Discharge (cms) | Iterations |
|---|---|---|---|---|
| 1838.61 | 0.00 | 0.00 | 0.00 | 1 |
| 1839.04 | 0.35 | 0.35 | 0.00 | 1 |
| 1839.23 | 0.70 | 0.70 | 0.00 | 1 |
| 1839.41 | 1.05 | 1.05 | 0.00 | 1 |
| 1839.57 | 1.40 | 1.40 | 0.00 | 1 |
| 1839.71 | 1.75 | 1.75 | 0.00 | 1 |
| 1839.86 | 2.10 | 2.10 | 0.00 | 1 |
| 1840.03 | 2.45 | 2.45 | 0.00 | 1 |
| 1840.10 | 2.60 | 2.60 | 0.00 | 1 |
| 1840.41 | 3.15 | 3.15 | 0.00 | 1 |
| 1840.60 | 3.50 | 3.43 | 0.07 | 8 |
| 1840.56 | 3.38 | 3.38 | 0.00 | Overtopping |

**Rating Curve Plot for Crossing: 126+460**



Straight Culvert

Inlet Elevation (invert): 1838.61 m, Outlet Elevation (invert): 1838.44 m

**Table 24- Culvert Summary Table: Culvert 1**

| Total Discharge (cms) | Culvert Discharge (cms) | Headwater Elevation (m) | Inlet Control Depth (m) | Outlet Control Depth (m) | Flow Type | Normal Depth (m) | Critical Depth (m) | Outlet Depth (m) | Tailwater Depth (m) | Outlet Velocity (m/s) | Tailwater Velocity (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 1838.61 | 0.000 | 0.000 | 0-NF | 0.000 | 0.000 | 0.146 | 0.000 | 0.000 | 0.000 |
| 0.35 | 0.35 | 1839.04 | 0.425 | 0.151 | 1-S2n | 0.197 | 0.313 | 0.225 | 0.043 | 2.304 | 2.346 |
| 0.70 | 0.70 | 1839.23 | 0.618 | 0.310 | 1-S2n | 0.278 | 0.448 | 0.332 | 0.065 | 2.649 | 3.081 |
| 1.05 | 1.05 | 1839.41 | 0.799 | 0.457 | 1-S2n | 0.341 | 0.556 | 0.419 | 0.083 | 2.886 | 3.609 |
| 1.40 | 1.40 | 1839.57 | 0.955 | 0.602 | 1-S2n | 0.396 | 0.645 | 0.495 | 0.099 | 3.075 | 4.035 |
| 1.75 | 1.75 | 1839.71 | 1.101 | 0.754 | 1-S2n | 0.446 | 0.725 | 0.564 | 0.114 | 3.240 | 4.397 |
| 2.10 | 2.10 | 1839.86 | 1.250 | 0.914 | 5-S2n | 0.493 | 0.797 | 0.628 | 0.127 | 3.396 | 4.717 |
| 2.45 | 2.45 | 1840.03 | 1.412 | 1.082 | 5-S2n | 0.538 | 0.862 | 0.688 | 0.140 | 3.542 | 5.003 |
| 2.60 | 2.60 | 1840.10 | 1.487 | 1.157 | 5-S2n | 0.556 | 0.888 | 0.712 | 0.145 | 3.605 | 5.118 |
| 3.15 | 3.15 | 1840.41 | 1.799 | 1.562 | 5-S2n | 0.623 | 0.973 | 0.797 | 0.163 | 3.836 | 5.506 |
| 3.50 | 3.43 | 1840.60 | 1.981 | 1.698 | 5-S2n | 0.656 | 1.009 | 0.837 | 0.175 | 3.956 | 5.729 |

Culvert Length: 9.50 m, Culvert Slope: 0.0179

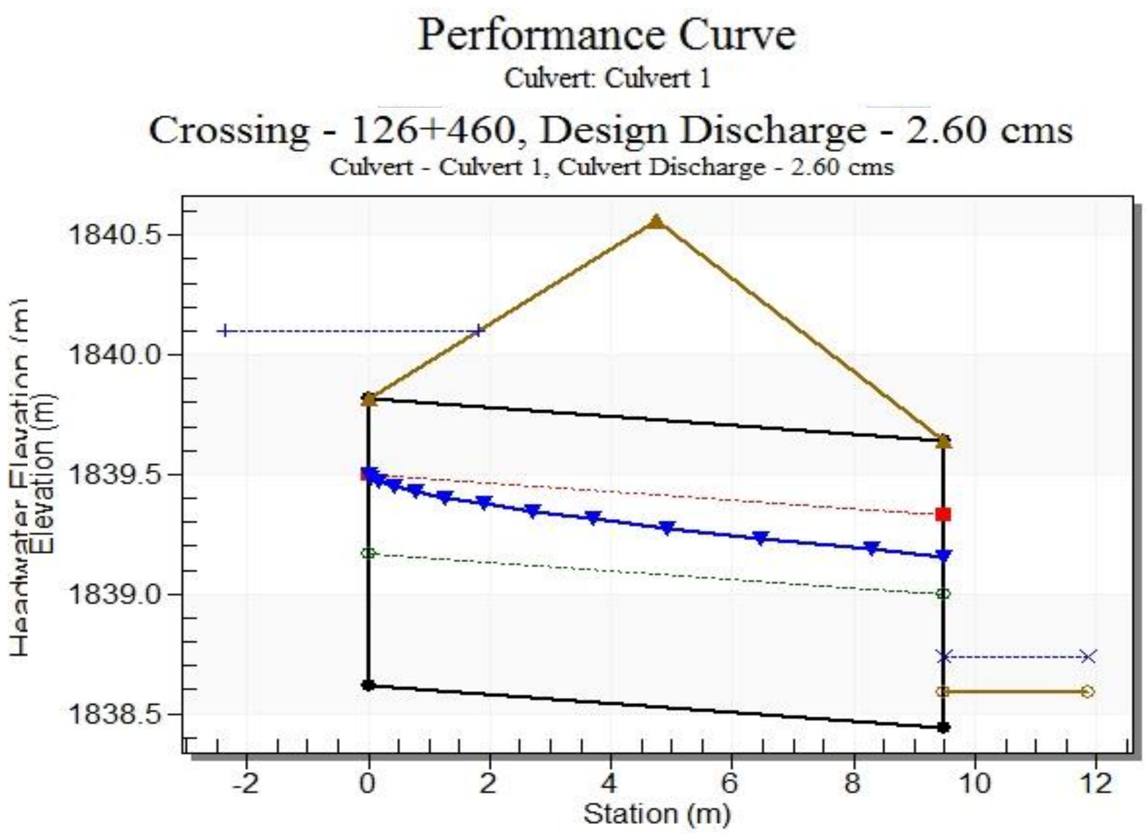



**Figure 24 Water Surface Profile Plot for Culvert: Culvert 1**

**Site Data - Culvert 1**

Site Data Option:  Culvert Invert Data

Inlet Station:  0.00 m

Inlet Elevation:  1838.61 m

Outlet Station:  9.50 m

Outlet Elevation:  1838.44 m

Number of Barrels:  1

**Culvert Data Summary - Culvert 1**

Barrel Shape:  Circular

Barrel Diameter:  1200.00 mm

Barrel Material:  Concrete

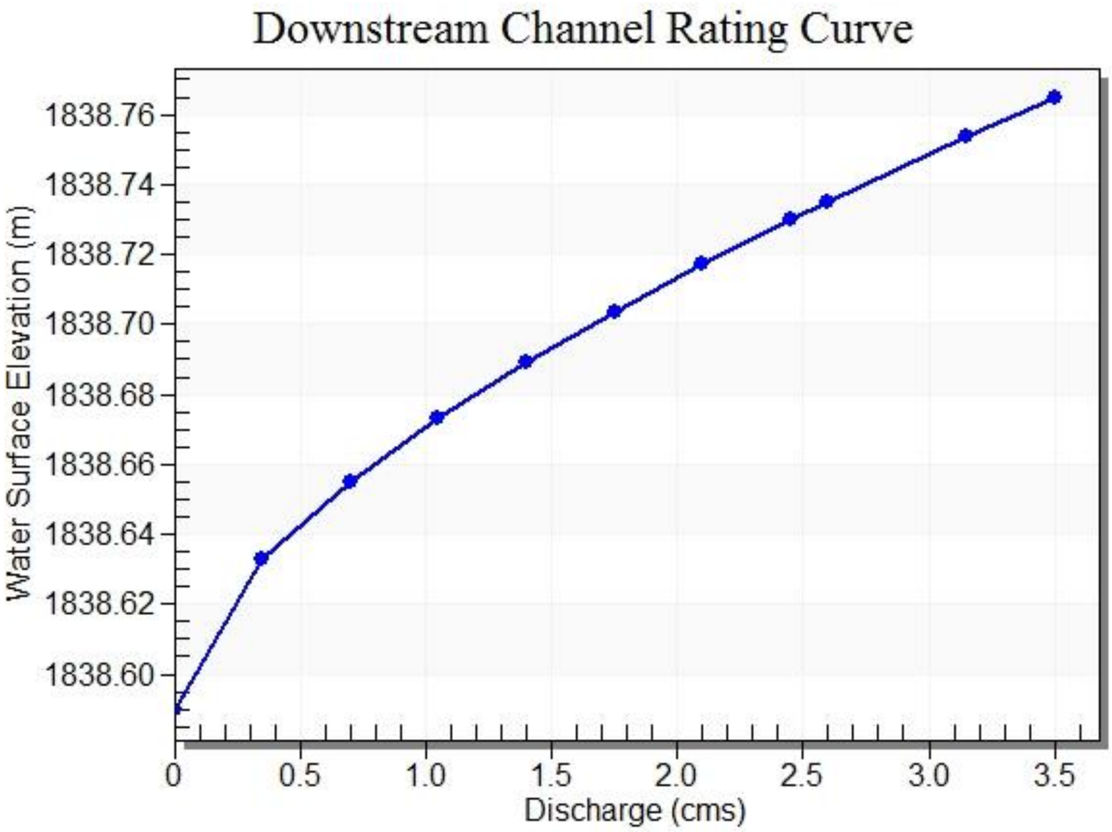
Barrel Manning's n:  0.0120

Culvert Type:  Straight

**Table 25- Downstream Channel Rating Curve (Crossing: 126+460)**

| Flow (cms) | Water Surface Elev (m) | Depth (m) | Velocity (m/s) | Shear (Pa) | Froude Number |
|---|---|---|---|---|---|
| 0.00 | 1838.59 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.35 | 1838.63 | 0.04 | 2.35 | 91.93 | 3.63 |
| 0.70 | 1838.65 | 0.06 | 3.08 | 139.99 | 3.86 |
| 1.05 | 1838.67 | 0.08 | 3.61 | 179.25 | 4.00 |
| 1.40 | 1838.69 | 0.10 | 4.04 | 213.77 | 4.09 |
| 1.75 | 1838.70 | 0.11 | 4.40 | 245.19 | 4.16 |
| 2.10 | 1838.72 | 0.13 | 4.72 | 274.29 | 4.22 |
| 2.45 | 1838.73 | 0.14 | 5.00 | 301.74 | 4.27 |
| 2.60 | 1838.74 | 0.15 | 5.12 | 312.99 | 4.29 |
| 3.15 | 1838.75 | 0.16 | 5.51 | 352.47 | 4.35 |
| 3.50 | 1838.76 | 0.17 | 5.73 | 376.43 | 4.38 |

**Tailwater Channel Data - 126+460**



## Table 26 *Yirgachefe _Hageremrim* Road flood analysis by rational method for area <=50 ha

| YIRGACHEFE-HAGEREMARIAM ROAD FLOOD ANALYSIS BY RATIONAL METHOD FOR AREAS <=50 ha | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C.ID | FLOW DIR. | Catch. Area (Ha)) | Catch. Area (km^2) | Elevation Differenc | Stream/overland | L[m] | Horisontal Dist | S (m/m) | Tc (min) channel | Tc (min) channel + | $I_{10}$(mm/hr) | $I_{25}$(mm/hr) | $I_{50}$(mm/hr) | C | $Q_{10}(m^3/s)$ | $Q_{25}$ $(m^3/s)$ | $Q_{50}$ $(m^3/s)$ |
| CA-05 | RIGHT | 49 | 0.49 | 20.786 | 0.506 | 506 | 0.498 | 0.042 | 10.798 | 0.180 | 120 | 145 | 165 | 0.2 | 3.269 | 4.345 | 5.394 |
| CA-03 | RIGHT | 43 | 0.43 | 11.917 | 0.582 | 582 | 0.543 | 0.022 | 15.442 | 0.257 | 102 | 122 | 140 | 0.2 | 2.439 | 3.208 | 4.017 |
| CA-04 | RIGHT | 38.9 | 0.39 | 17.165 | 0.676 | 676 | 0.657 | 0.026 | 15.978 | 0.266 | 100 | 120.5 | 138.5 | 0.2 | 2.163 | 2.867 | 3.595 |
| CA-05 | RIGHT | 27.8 | 0.28 | 18.744 | 0.529 | 529 | 0.506 | 0.037 | 11.690 | 0.195 | 117 | 142 | 163 | 0.2 | 1.808 | 2.414 | 3.023 |
| CA-09 | RIGHT | 45.9 | 0.46 | 29 | 0.806 | 806 | 0.792 | 0.037 | 15.777 | 0.263 | 128 | 151 | 173 | 0.2 | 3.267 | 4.239 | 5.298 |
| CA-10 | RIGHT | 40.681 | 0.41 | 20 | 0.77 | 770 | 0.712 | 0.028 | 17.001 | 0.283 | 138 | 167 | 188 | 0.2 | 3.121 | 4.155 | 5.103 |
| CA-11 | RIGHT | 7.9 | 0.08 | 27 | 0.601 | 601 | 0.557 | 0.048 | 11.464 | 0.191 | 140 | 170 | 190 | 0.2 | 0.615 | 0.821 | 1.001 |
| CA-13 | RIGHT | 4.95 | 0.05 | 56.7 | 0.767 | 767 | 0.709 | 0.080 | 11.125 | 0.185 | 121 | 146 | 166 | 0.2 | 0.333 | 0.442 | 0.548 |
| CA-14 | LEFT | 8.773 | 0.09 | 44.4 | 0.767 | 767 | 1.709 | 0.026 | 17.497 | 0.292 | 120 | 146 | 166 | 0.15 | 0.439 | 0.588 | 0.729 |
| CA-15 | LEFT | 8.9 | 0.09 | 43.54 | 0.767 | 767 | 2.709 | 0.016 | 21.239 | 0.354 | 102 | 146 | 166 | 0.15 | 0.379 | 0.596 | 0.739 |
| CA-16 | LEFT | 34 | 0.34 | 34.6 | 0.767 | 767 | 3.709 | 0.009 | 26.464 | 0.441 | 100 | 146 | 166 | 0.15 | 1.418 | 2.277 | 2.824 |
| CA-18 | RIGHT | 14.89 | 0.15 | 34.98 | 0.767 | 767 | 4.709 | 0.007 | 29.020 | 0.484 | 117 | 146 | 166 | 0.2 | 0.969 | 1.330 | 1.649 |
| CA-19 | RIGHT | 4.449 | 0.04 | 45.3 | 0.767 | 767 | 5.709 | 0.008 | 28.255 | 0.471 | 128 | 146 | 166 | 0.2 | 0.317 | 0.397 | 0.493 |
| CA-20 | RIGHT | 7.99 | 0.08 | 43.5 | 0.767 | 767 | 6.709 | 0.006 | 30.663 | 0.511 | 138 | 146 | 166 | 0.2 | 0.613 | 0.713 | 0.885 |
| CA-21 | RIGHT | 21.45 | 0.21 | 34.5 | 0.767 | 767 | 7.709 | 0.004 | 35.635 | 0.594 | 140 | 146 | 166 | 0.2 | 1.670 | 1.915 | 2.376 |
| CA-22 | RIGHT | 7.98 | 0.08 | 34.5 | 0.767 | 767 | 8.709 | 0.004 | 37.442 | 0.624 | 121 | 146 | 166 | 0.2 | 0.537 | 0.713 | 0.884 |
| CA-23 | LEFT | 7.97 | 0.08 | 45.5 | 0.767 | 767 | 9.709 | 0.005 | 34.975 | 0.583 | 121 | 146 | 166 | 0.15 | 0.402 | 0.534 | 0.662 |
| CA-24 | LEFT | 18.96 | 0.19 | 37.8 | 0.875 | 875 | 10.709 | 0.004 | 42.994 | 0.717 | 121 | 146 | 166 | 0.15 | 0.957 | 1.270 | 1.575 |
| CA-26 | LEFT | 17.9 | 0.18 | 38.6 | 0.875 | 875 | 11.709 | 0.003 | 44.201 | 0.737 | 121 | 146 | 166 | 0.15 | 0.903 | 1.199 | 1.487 |
| CA-27 | LEFT | 20.45 | 0.20 | 38.6 | 0.875 | 875 | 12.709 | 0.003 | 45.694 | 0.762 | 121 | 146 | 166 | 0.15 | 1.032 | 1.370 | 1.699 |
| CA-28 | LEFT | 32.8 | 0.33 | 22.5 | 0.875 | 875 | 13.709 | 0.002 | 58.658 | 0.978 | 120 | 146 | 166 | 0.15 | 1.641 | 2.197 | 2.725 |
| CA-29 | LEFT | 16.9 | 0.17 | 23.4 | 0.875 | 875 | 14.709 | 0.002 | 59.406 | 0.990 | 102 | 146 | 166 | 0.15 | 0.719 | 1.132 | 1.404 |
| CA-31 | LEFT | 33.63 | 0.34 | 22.4 | 0.875 | 875 | 15.709 | 0.001 | 62.107 | 1.035 | 100 | 146 | 166 | 0.15 | 1.402 | 2.252 | 2.794 |
| CA-34 | LEFT | 39.5 | 0.40 | 20.66 | 0.875 | 875 | 16.709 | 0.001 | 65.812 | 1.097 | 117 | 146 | 166 | 0.15 | 1.927 | 2.645 | 3.281 |
| CA-36 | LEFT | 8.92 | 0.09 | 20.4 | 0.767 | 767 | 17.709 | 0.001 | 61.858 | 1.031 | 128 | 146 | 166 | 0.15 | 0.476 | 0.597 | 0.741 |
| CA-38 | LEFT | 40.05 | 0.40 | 10.55 | 0.767 | 767 | 18.709 | 0.001 | 82.775 | 1.380 | 138 | 146 | 166 | 0.15 | 2.305 | 2.682 | 3.327 |
| CA-39 | LEFT | 20.85 | 0.21 | 15.55 | 0.767 | 767 | 19.709 | 0.001 | 72.175 | 1.203 | 140 | 146 | 166 | 0.15 | 1.217 | 1.396 | 1.732 |
| CA-40 | LEFT | 40.69 | 0.41 | 15.85 | 0.954 | 954 | 20.709 | 0.001 | 84.902 | 1.415 | 121 | 146 | 166 | 0.15 | 2.053 | 2.725 | 3.380 |
| CA-43 | LEFT | 32.73 | 0.33 | 16.77 | 0.954 | 954 | 21.709 | 0.001 | 84.583 | 1.410 | 121 | 146 | 166 | 0.15 | 1.651 | 2.192 | 2.719 |
| CA-44 | LEFT | 27.48 | 0.27 | 12.4 | 0.954 | 954 | 22.709 | 0.001 | 97.410 | 1.623 | 121 | 146 | 166 | 0.15 | 1.387 | 1.840 | 2.283 |
| CA-45 | LEFT | 20.69 | 0.21 | 17.88 | 0.954 | 954 | 23.709 | 0.001 | 85.414 | 1.424 | 120 | 146 | 166 | 0.15 | 1.035 | 1.386 | 1.719 |
| CA-46 | LEFT | 19.45 | 0.19 | 16.97 | 0.954 | 954 | 24.709 | 0.001 | 88.728 | 1.479 | 102 | 146 | 166 | 0.15 | 0.827 | 1.303 | 1.616 |
| CA-47 | LEFT | 18.92 | 0.19 | 20.66 | 0.954 | 954 | 25.709 | 0.001 | 83.235 | 1.387 | 100 | 146 | 166 | 0.15 | 0.789 | 1.267 | 1.572 |
| CA-51 | LEFT | 14.98 | 0.15 | 20.4 | 0.954 | 954 | 26.709 | 0.001 | 84.974 | 1.416 | 117 | 146 | 166 | 0.15 | 0.731 | 1.003 | 1.244 |
| CA-52 | LEFT | 14.458 | 0.14 | 10.55 | 0.767 | 767 | 27.709 | 0.000 | 97.181 | 1.620 | 128 | 146 | 166 | 0.15 | 0.772 | 0.968 | 1.201 |
| CA-54 | LEFT | 17.45 | 0.17 | 15.55 | 0.767 | 767 | 28.709 | 0.001 | 84.147 | 1.402 | 138 | 146 | 166 | 0.15 | 1.004 | 1.169 | 1.450 |
| CA-56 | LEFT | 18.12 | 0.18 | 15.85 | 0.767 | 767 | 29.709 | 0.001 | 84.669 | 1.411 | 140 | 146 | 166 | 0.15 | 1.058 | 1.214 | 1.505 |
| CA-58 | LEFT | 15.99 | 0.16 | 16.77 | 0.767 | 767 | 30.709 | 0.001 | 83.867 | 1.398 | 121 | 146 | 166 | 0.15 | 0.807 | 1.071 | 1.328 |
| CA-59 | LEFT | 16 | 0.16 | 12.4 | 0.767 | 767 | 31.709 | 0.000 | 96.125 | 1.602 | 121 | 146 | 166 | 0.15 | 0.807 | 1.072 | 1.329 |
| CA-60 | LEFT | 17.05 | 0.17 | 17.88 | 0.767 | 767 | 32.709 | 0.001 | 83.832 | 1.397 | 121 | 146 | 166 | 0.15 | 0.860 | 1.142 | 1.416 |
| CA-61 | LEFT | 17.604 | 0.18 | 16.97 | 0.767 | 767 | 33.709 | 0.001 | 86.699 | 1.445 | 121 | 146 | 166 | 0.15 | 0.888 | 1.179 | 1.462 |
| CA-62 | LEFT | 23.8 | 0.24 | 20.66 | 0.767 | 767 | 34.709 | 0.001 | 80.968 | 1.349 | 120 | 146 | 166 | 0.15 | 1.191 | 1.594 | 1.977 |
| CA-63 | LEFT | 41.6 | 0.42 | 20.4 | 0.767 | 767 | 35.709 | 0.001 | 82.337 | 1.372 | 102 | 146 | 166 | 0.15 | 1.769 | 2.786 | 3.456 |
| CA-64 | LEFT | 9.7 | 0.10 | 10.55 | 0.767 | 767 | 36.709 | 0.000 | 109.028 | 1.817 | 100 | 146 | 166 | 0.15 | 0.404 | 0.650 | 0.806 |
| CA-65 | LEFT | 15.47 | 0.15 | 15.55 | 0.767 | 767 | 37.709 | 0.000 | 94.063 | 1.568 | 117 | 146 | 166 | 0.15 | 0.755 | 1.036 | 1.285 |
| CA-67 | LEFT | 31.98 | 0.32 | 15.85 | 0.767 | 767 | 38.709 | 0.000 | 94.335 | 1.572 | 128 | 146 | 166 | 0.15 | 1.707 | 2.142 | 2.656 |
| CA-68 | LEFT | 8.92 | 0.09 | 16.77 | 0.767 | 767 | 39.709 | 0.000 | 93.150 | 1.553 | 138 | 146 | 166 | 0.15 | 0.513 | 0.597 | 0.741 |
| CA-70 | LEFT | 18.8 | 0.19 | 12.4 | 0.767 | 767 | 40.709 | 0.000 | 106.465 | 1.774 | 140 | 146 | 166 | 0.15 | 1.098 | 1.259 | 1.562 |
| CA-71 | RIGHT | 22.98 | 0.23 | 17.88 | 0.767 | 767 | 41.709 | 0.000 | 92.583 | 1.543 | 121 | 146 | 166 | 0.2 | 1.546 | 2.052 | 2.545 |
| CA-74 | RIGHT | 30.3 | 0.30 | 16.97 | 0.767 | 767 | 42.709 | 0.000 | 95.501 | 1.592 | 121 | 146 | 166 | 0.2 | 2.038 | 2.706 | 3.356 |
| CA-75 | RIGHT | 12.18 | 0.12 | 20.66 | 0.767 | 767 | 43.709 | 0.000 | 88.961 | 1.483 | 121 | 146 | 166 | 0.2 | 0.819 | 1.088 | 1.349 |
| CA-76 | RIGHT | 25.38 | 0.25 | 20.4 | 0.767 | 767 | 44.709 | 0.000 | 90.252 | 1.504 | 120 | 146 | 166 | 0.2 | 1.693 | 2.266 | 2.811 |
| CA-77 | RIGHT | 9.57 | 0.10 | 10.55 | 0.987 | 987 | 45.709 | 0.000 | 141.646 | 2.361 | 102 | 146 | 166 | 0.2 | 0.543 | 0.855 | 1.060 |
| CA-79 | LEFT | 18.66 | 0.19 | 15.55 | 0.789 | 789 | 46.709 | 0.000 | 104.663 | 1.744 | 100 | 146 | 166 | 0.15 | 0.778 | 1.250 | 1.550 |
| CA-80 | LEFT | 25.98 | 0.26 | 15.85 | 0.875 | 875 | 47.709 | 0.000 | 112.420 | 1.874 | 117 | 146 | 166 | 0.15 | 1.268 | 1.740 | 2.158 |
| CA-81 | LEFT | 12.87 | 0.13 | 16.77 | 1.02 | 1020 | 48.709 | 0.000 | 123.074 | 2.051 | 128 | 146 | 166 | 0.15 | 0.687 | 0.862 | 1.069 |
| CA-82 | LEFT | 16.84 | 0.17 | 12.4 | 1.001 | 1001 | 49.709 | 0.000 | 138.556 | 2.309 | 138 | 146 | 166 | 0.15 | 0.969 | 1.128 | 1.399 |
| CA-83 | LEFT | 42.47 | 0.42 | 17.88 | 0.767 | 767 | 50.709 | 0.000 | 100.280 | 1.671 | 140 | 146 | 166 | 0.15 | 2.479 | 2.844 | 3.528 |
| CA-84 | LEFT | 30.9 | 0.31 | 16.97 | 0.767 | 767 | 51.709 | 0.000 | 103.267 | 1.721 | 121 | 146 | 166 | 0.15 | 1.559 | 2.069 | 2.567 |
| CA-86 | LEFT | 9.87 | 0.10 | 20.66 | 0.767 | 767 | 52.709 | 0.000 | 96.034 | 1.601 | 121 | 146 | 166 | 0.15 | 0.498 | 0.661 | 0.820 |
| CA-87 | LEFT | 7.88 | 0.08 | 20.4 | 0.767 | 767 | 53.709 | 0.000 | 97.277 | 1.621 | 121 | 146 | 166 | 0.15 | 0.398 | 0.528 | 0.655 |
| CA-89 | LEFT | 33 | 0.33 | 10.55 | 0.767 | 767 | 54.709 | 0.000 | 128.379 | 2.140 | 117 | 146 | 166 | 0.15 | 1.610 | 2.210 | 2.741 |
| CA-90 | RIGHT | 21.9 | 0.22 | 15.55 | 0.767 | 767 | 55.709 | 0.000 | 110.338 | 1.839 | 128 | 146 | 166 | 0.2 | 1.559 | 1.956 | 2.426 |
| CA-91 | RIGHT | 17.57 | 0.18 | 15.85 | 0.767 | 767 | 56.709 | 0.000 | 110.279 | 1.838 | 138 | 146 | 166 | 0.2 | 1.348 | 1.569 | 1.946 |
| CA-92 | RIGHT | 19.67 | 0.20 | 16.77 | 0.767 | 767 | 57.709 | 0.000 | 108.535 | 1.809 | 140 | 146 | 166 | 0.2 | 1.531 | 1.756 | 2.179 |
| CA-93 | RIGHT | 9.88 | 0.10 | 12.4 | 0.767 | 767 | 58.709 | 0.000 | 123.680 | 2.061 | 121 | 146 | 166 | 0.2 | 0.665 | 0.882 | 1.094 |

**Table 27 Yirgachefe-Hageremariam Road flood analysis by SCS CN method for area >50 ha**

YIRGACHEFE-HAGEREMARIAM ROAD FLOOD ANALYSIS BY SCS CN METHOD FOR AREAS > 50 ha

| Catch. Area (Ha)) | Catch. Area (km^2) | Elevation Difference [m] | Stream/overland Length [Km] | L[m] | Horisontal Dist (km) | S (m/m) | Tc (min) channel + ovl | Tc (HR) channel + ovl | Hydrologic Soil Group | CN | RAINFALL REGION | $P_{25}$ | $P_{50}$ | $P_{100}$ | Ia (From Table) | $Q_{25}$ (mm) | $Q_{50}$ (mm) | $Q_{100}$ (mm) | $Ia/P_{25}$ | $Ia/P_{50}$ | $Ia/P_{100}$ | $q_u(m^3/s/100ha/mm)$ | $q_u(m^3/s/100ha/mm)$ | $q_u(m^3/s/100ha/mm)$ | $Q_{25}$ $(m^3/s)$ | $Q_{50}$ $(m^3/s)$ | $Q_{100}$ $(m^3/s)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60.98 | 0.61 | 45.00 | 3.25 | 3250.0 | 3.11 | 0.01 | 61.81 | 1.03 | A | 88 | B2 | 118 | 132 | 147 | 6.90 | 35.00 | 43.00 | 51.00 | 0.06 | 0.05 | 0.05 | 0.47 | 0.47 | 0.47 | 9.95 | 12.23 | 14.50 |
| 174.59 | 1.75 | 13.73 | 1.02 | 1020.0 | 0.97 | 0.01 | 27.31 | 0.46 | A | 88 | B2 | 118 | 132 | 147 | 6.90 | 31.00 | 39.00 | 47.00 | 0.06 | 0.05 | 0.05 | 0.41 | 0.41 | 0.41 | 22.16 | 27.88 | 33.87 |
| 959.70 | 9.60 | 45.00 | 3.25 | 3250.0 | 5.11 | 0.01 | 75.34 | 1.26 | B | 88 | B2 | 118 | 132 | 147 | 6.90 | 32.00 | 40.00 | 48.00 | 0.06 | 0.05 | 0.05 | 0.39 | 0.39 | 0.46 | 120.58 | 150.72 | 212.77 |
| 59.80 | 0.60 | 343.02 | 3.11 | 3110.0 | 3.07 | 0.11 | 26.56 | 0.44 | B | 88 | B2 | 118 | 132 | 147 | 6.90 | 61.00 | 70.00 | 78.00 | 0.06 | 0.05 | 0.05 | 0.48 | 0.48 | 0.48 | 17.44 | 20.02 | 22.30 |
| 95.27 | 0.95 | 882.30 | 3.31 | 3310.0 | 3.13 | 0.28 | 19.26 | 0.32 | B | 88 | B2 | 118 | 132 | 147 | 6.90 | 31.00 | 39.00 | 47.00 | 0.06 | 0.05 | 0.05 | 0.41 | 0.41 | 0.41 | 12.18 | 15.32 | 18.48 |
| 2248.90 | 22.49 | 417.19 | 3.71 | 3710.0 | 3.71 | 0.11 | 30.12 | 0.50 | B | 88 | B2 | 118 | 132 | 147 | 6.90 | 35.00 | 43.00 | 51.00 | 0.06 | 0.05 | 0.05 | 0.41 | 0.41 | 0.48 | 321.50 | 394.99 | 547.04 |
| 82.40 | 0.82 | 42.89 | 1.53 | 1530.0 | 1.49 | 0.03 | 27.37 | 0.46 | B | 88 | B2 | 118 | 132 | 147 | 6.90 | 35.00 | 43.00 | 51.00 | 0.06 | 0.05 | 0.05 | 0.41 | 0.41 | 0.48 | 11.81 | 14.51 | 20.08 |
| 72.45 | 0.72 | 427.69 | 3.71 | 3710.0 | 3.63 | 0.12 | 29.57 | 0.49 | C | 88 | B2 | 118 | 132 | 147 | 6.90 | 44.00 | 52.00 | 61.00 | 0.06 | 0.05 | 0.05 | 0.48 | 0.48 | 0.48 | 15.21 | 17.97 | 21.09 |
| 53.45 | 0.53 | 33.46 | 1.00 | 1000.0 | 0.92 | 0.04 | 18.42 | 0.31 | C | 88 | B2 | 118 | 132 | 147 | 6.90 | 35.00 | 43.00 | 51.00 | 0.06 | 0.05 | 0.05 | 0.41 | 0.48 | 0.48 | 7.72 | 11.05 | 13.11 |
| 78.21 | 0.78 | 172.70 | 2.43 | 2430.0 | 2.41 | 0.07 | 26.50 | 0.44 | B | 88 | B2 | 118 | 132 | 147 | 6.90 | 44.00 | 52.00 | 61.00 | 0.06 | 0.05 | 0.05 | 0.48 | 0.48 | 0.48 | 16.45 | 19.45 | 22.81 |
| 60.05 | 0.60 | 105.20 | 1.23 | 1230.0 | 1.19 | 0.09 | 14.95 | 0.25 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 15.00 | 22.00 | 30.00 | 0.13 | 0.12 | 0.10 | 0.39 | 0.39 | 0.42 | 3.52 | 5.17 | 7.65 |
| 595.76 | 5.96 | 478.50 | 4.08 | 4080.0 | 3.97 | 0.12 | 31.41 | 0.52 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 43.00 | 49.00 | 59.00 | 0.13 | 0.12 | 0.10 | 0.48 | 0.48 | 0.48 | 122.08 | 139.11 | 167.50 |
| 72.65 | 0.73 | 480.70 | 2.56 | 2560.0 | 2.44 | 0.20 | 18.41 | 0.31 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 31.00 | 39.00 | 47.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.41 | 0.41 | 9.29 | 11.69 | 14.09 |
| 112.50 | 1.13 | 83.90 | 0.95 | 954.0 | 0.93 | 0.09 | 12.35 | 0.21 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 35.00 | 43.00 | 51.00 | 0.13 | 0.12 | 0.10 | 0.48 | 0.48 | 0.48 | 19.01 | 23.36 | 27.71 |
| 218.41 | 2.18 | 250.20 | 1.05 | 1050.0 | 1.01 | 0.25 | 8.84 | 0.15 | C | 77 | B2 | 118 | 132 | 147 | 15.20 | 44.00 | 52.00 | 61.00 | 0.13 | 0.12 | 0.10 | 0.48 | 0.48 | 0.48 | 46.52 | 54.98 | 64.49 |
| 55.04 | 0.55 | 617.90 | 4.57 | 4570.0 | 4.48 | 0.14 | 32.35 | 0.54 | C | 77 | B2 | 118 | 132 | 147 | 15.20 | 35.00 | 43.00 | 51.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.48 | 0.48 | 7.85 | 11.27 | 13.37 |
| 270.97 | 2.71 | 114.10 | 1.12 | 1120.0 | 1.03 | 0.11 | 12.77 | 0.21 | A | 77 | B2 | 118 | 132 | 147 | 15.20 | 35.00 | 43.00 | 51.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.48 | 0.48 | 39.31 | 56.25 | 66.71 |
| 491.77 | 4.92 | 53.40 | 1.36 | 1360.0 | 1.35 | 0.04 | 22.16 | 0.37 | A | 87 | B2 | 118 | 132 | 147 | 7.60 | 32.00 | 40.00 | 48.00 | 0.06 | 0.06 | 0.05 | 0.41 | 0.41 | 0.41 | 64.72 | 80.90 | 97.42 |
| 96.70 | 0.97 | 68.10 | 1.99 | 1990.0 | 1.87 | 0.04 | 30.06 | 0.50 | A | 87 | B2 | 118 | 132 | 147 | 7.60 | 35.00 | 43.00 | 51.00 | 0.06 | 0.06 | 0.05 | 0.48 | 0.48 | 0.48 | 16.14 | 19.83 | 23.52 |
| 62.20 | 0.62 | 179.20 | 1.69 | 1690.0 | 1.58 | 0.11 | 16.99 | 0.28 | A | 87 | B2 | 118 | 132 | 147 | 7.60 | 55.00 | 62.00 | 73.00 | 0.06 | 0.06 | 0.05 | 0.48 | 0.48 | 0.48 | 16.47 | 18.56 | 21.86 |
| 88.82 | 0.89 | 664.40 | 5.65 | 5650.0 | 5.49 | 0.12 | 39.79 | 0.66 | B | 87 | B2 | 118 | 132 | 147 | 7.60 | 29.00 | 36.00 | 44.00 | 0.06 | 0.06 | 0.05 | 0.41 | 0.41 | 0.41 | 10.43 | 12.95 | 16.13 |
| 175.92 | 1.76 | 17.00 | 5.65 | 5650.0 | 6.49 | 0.00 | 181.90 | 3.03 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 29.00 | 36.00 | 44.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.41 | 0.41 | 20.67 | 25.65 | 31.94 |
| 157.23 | 1.57 | 19.00 | 5.65 | 5650.0 | 7.49 | 0.00 | 184.24 | 3.07 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 29.00 | 36.00 | 44.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.41 | 0.41 | 18.47 | 22.93 | 28.55 |
| 65.06 | 0.65 | 23.00 | 5.65 | 5650.0 | 8.49 | 0.00 | 179.48 | 2.99 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 29.00 | 36.00 | 44.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.41 | 0.41 | 7.64 | 9.49 | 11.81 |
| 61.13 | 0.61 | 34.00 | 5.65 | 5650.0 | 9.49 | 0.00 | 160.58 | 2.68 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 29.00 | 36.00 | 44.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.41 | 0.41 | 7.18 | 8.91 | 11.10 |
| 64.92 | 0.65 | 53.40 | 5.65 | 5650.0 | 10.49 | 0.01 | 139.65 | 2.33 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 29.00 | 36.00 | 44.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.41 | 0.41 | 7.63 | 9.47 | 11.79 |
| 111.89 | 1.12 | 68.10 | 5.65 | 5650.0 | 11.49 | 0.01 | 131.45 | 2.19 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 29.00 | 36.00 | 44.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.41 | 0.41 | 13.14 | 16.32 | 20.32 |
| 143.94 | 1.44 | 21.00 | 5.65 | 5650.0 | 12.49 | 0.00 | 217.03 | 3.62 | B | 77 | B2 | 118 | 132 | 147 | 15.20 | 29.00 | 36.00 | 44.00 | 0.13 | 0.12 | 0.10 | 0.41 | 0.41 | 0.41 | 16.91 | 20.99 | 26.14 |

**Table 28 Yirgachfe Bridge station HEC_RAS output**

| Plan: Yirgachefe WOGIDA YIRGACHEFE RS: 760.00 Profile: 5year | | | | | |
|---|---|---|---|---|---|
| E.G. Elev (m) | 1837.98 | Element | Left OB | Channel | Right OB |
| Vel Head (m) | - | Wt. n-Val. | 0.033 | 0.033 | 0.033 |
| W.S. Elev (m) | 1837.98 | Reach Len. (m) | 40.01 | 40 | 40.03 |
| Crit W.S. (m) | | Flow Area (m2) | 109.51 | 414.48 | 182.58 |
| E.G. Slope (m/m) | - | Area (m2) | 109.51 | 414.48 | 182.58 |
| Q Total (m3/s) | 5 | Flow (m3/s) | 0.58 | 3.25 | 1.17 |
| Top Width (m) | 20 | Top Width (m) | 15.96 | 47.09 | 16.95 |
| Vel Total (m/s) | 0.01 | Avg. Vel. (m/s) | 0.01 | 0.01 | 0.01 |
| Max Chl Dpth (m) | 11.29 | Hydr. Depth (m) | 6.86 | 8.8 | 10.77 |
| Conv. Total (m3/s) | 82231.6 | Conv. (m3/s) | 9570.1 | 53475 | 19186.4 |
| Length Wtd. (m) | 40.01 | Wetted Per. (m) | 22.36 | 47.18 | 28.27 |
| Min Ch El (m) | 1827.73 | Shear (N/m2) | 0 | 0 | 0 |
| Alpha | 1.06 | Stream Power (N/m s) | 0 | 0 | 0 |
| Frctn Loss (m) | 0 | Cum Volume (1000 m3) | 47.89 | 178.13 | 61.29 |
| C and E Loss (m) | 0 | Cum SA (1000 m2) | 9.99 | 29.62 | 7.99 |

**Table 29 *Yirgachefe* Bridge profile output of HEC_RAS**

| Reach | River Sta | Profile | Q Total | Min Ch El | W.S. Elev | Crit W.S. | E.G. Elev | Vel Chnl | Flow Area | Top Width |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | (m3/s) | (m) | (m) | (m) | (m) | (m/s) | (m2) | (m) |
| YIRGACHEFE | 800 | 5year | 5 | 1830.1 | 1837.98 | | 1837.98 | 0.01 | 524.53 | 20 |
| YIRGACHEFE | 800 | 10year | 8 | 1830.1 | 1838.08 | | 1838.08 | 0.02 | 532.54 | 20 |
| YIRGACHEFE | 800 | 50year | 13 | 1830.1 | 1838.19 | | 1838.19 | 0.03 | 541.47 | 20 |
| | | | | | | | | | | |
| YIRGACHEFE | 760 | 5year | 5 | 1827.73 | 1837.98 | | 1837.98 | 0.01 | 706.57 | 20 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| YIRGACHE FE | 760 | 10year | 8 | 1827.73 | 1838.08 | | 1838.08 | 0.01 | 714.58 | 20 |
| YIRGACHE FE | 760 | 50year | 13 | 1827.73 | 1838.19 | | 1838.19 | 0.02 | 723.51 | 20 |
| | | | | | | | | | | |
| YIRGACHE FE | 720 | 5year | 5 | 1825.41 | 1837.98 | | 1837.98 | 0.01 | 882 | 20 |
| YIRGACHE FE | 720 | 10year | 8 | 1825.41 | 1838.08 | | 1838.08 | 0.01 | 890.01 | 20 |
| YIRGACHE FE | 720 | 50year | 13 | 1825.41 | 1838.19 | | 1838.19 | 0.02 | 898.94 | 20 |
| | | | | | | | | | | |
| YIRGACHE FE | 680 | 5year | 5 | 1826.76 | 1837.98 | 1826.36 | 1837.98 | 0.01 | 858.05 | 20 |
| YIRGACHE FE | 680 | 10year | 8 | 1826.76 | 1838.08 | 1826.47 | 1838.08 | 0.01 | 866.06 | 20 |
| YIRGACHE FE | 680 | 50year | 13 | 1826.76 | 1838.19 | 1826.6 | 1838.19 | 0.02 | 874.99 | 20 |
| | | | | | | | | | | |
| YIRGACHE FE | 652.44 | | Bridge | | | | | | | |
| | | | | | | | | | | |
| YIRGACHE FE | 640 | 5year | 5 | 1828.07 | 1837.98 | | 1837.98 | 0.01 | 778.16 | 20 |
| YIRGACHE FE | 640 | 10year | 8 | 1828.07 | 1838.08 | | 1838.08 | 0.01 | 786.17 | 20 |
| YIRGACHE FE | 640 | 50year | 13 | 1828.07 | 1838.19 | | 1838.19 | 0.02 | 795.1 | 20 |
| | | | | | | | | | | |
| YIRGACHE FE | 600 | 5year | 5 | 1828.7 | 1837.98 | | 1837.98 | 0.01 | 722.3 | 20 |
| YIRGACHE FE | 600 | 10year | 8 | 1828.7 | 1838.08 | | 1838.08 | 0.01 | 730.32 | 20 |
| YIRGACHE FE | 600 | 50year | 13 | 1828.7 | 1838.19 | | 1838.19 | 0.02 | 739.25 | 20 |
| | | | | | | | | | | |
| YIRGACHE FE | 560 | 5year | 5 | 1829.33 | 1837.98 | | 1837.98 | 0.01 | 670.2 | 20 |
| YIRGACHE FE | 560 | 10year | 8 | 1829.33 | 1838.08 | | 1838.08 | 0.01 | 678.22 | 20 |
| YIRGACHE FE | 560 | 50year | 13 | 1829.33 | 1838.19 | | 1838.19 | 0.02 | 687.15 | 20 |
| | | | | | | | | | | |
| YIRGACHE FE | 520 | 5year | 5 | 1829.96 | 1837.98 | | 1837.98 | 0.01 | 618.08 | 20 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| YIRGACHEFE | 520 | 10year | 8 | 1829.96 | 1838.08 | | 1838.08 | 0.01 | 626.09 | 20 |
| YIRGACHEFE | 520 | 50year | 13 | 1829.96 | 1838.19 | | 1838.19 | 0.02 | 635.02 | 20 |
| | | | | | | | | | | |
| YIRGACHEFE | 480 | 5year | 5 | 1830.6 | 1837.98 | | 1837.98 | 0.01 | 565.73 | 20 |
| YIRGACHEFE | 480 | 10year | 8 | 1830.6 | 1838.08 | | 1838.08 | 0.02 | 573.74 | 20 |
| YIRGACHEFE | 480 | 50year | 13 | 1830.6 | 1838.19 | | 1838.19 | 0.02 | 582.67 | 20 |
| | | | | | | | | | | |
| YIRGACHEFE | 440 | 5year | 5 | 1831.25 | 1837.98 | | 1837.98 | 0.01 | 513.23 | 20 |
| YIRGACHEFE | 440 | 10year | 8 | 1831.25 | 1838.08 | | 1838.08 | 0.02 | 521.24 | 20 |
| YIRGACHEFE | 440 | 50year | 13 | 1831.25 | 1838.19 | | 1838.19 | 0.03 | 530.17 | 20 |
| | | | | | | | | | | |
| YIRGACHEFE | 400 | 5year | 5 | 1832.37 | 1837.98 | | 1837.98 | 0.01 | 433.31 | 20 |
| YIRGACHEFE | 400 | 10year | 8 | 1832.37 | 1838.08 | | 1838.08 | 0.02 | 441.32 | 20 |
| YIRGACHEFE | 400 | 50year | 13 | 1832.37 | 1838.19 | | 1838.19 | 0.03 | 450.25 | 20 |
| | | | | | | | | | | |
| YIRGACHEFE | 360 | 5year | 5 | 1833.5 | 1837.98 | | 1837.98 | 0.02 | 346.24 | 20 |
| YIRGACHEFE | 360 | 10year | 8 | 1833.5 | 1838.08 | | 1838.08 | 0.02 | 354.25 | 20 |
| YIRGACHEFE | 360 | 50year | 13 | 1833.5 | 1838.19 | | 1838.19 | 0.04 | 363.18 | 20 |
| | | | | | | | | | | |
| YIRGACHEFE | 320 | 5year | 5 | 1834.59 | 1837.98 | | 1837.98 | 0.02 | 258.88 | 20 |
| YIRGACHEFE | 320 | 10year | 8 | 1834.59 | 1838.08 | | 1838.08 | 0.03 | 266.9 | 20 |
| YIRGACHEFE | 320 | 50year | 13 | 1834.59 | 1838.19 | | 1838.19 | 0.05 | 275.81 | 20 |
| | | | | | | | | | | |
| YIRGACHEFE | 280 | 5year | 5 | 1835.69 | 1837.98 | | 1837.98 | 0.03 | 171.19 | 20 |
| YIRGACHEFE | 280 | 10year | 8 | 1835.69 | 1838.08 | | 1838.08 | 0.05 | 179.19 | 20 |
| YIRGACHE | 280 | 50ye | 13 | 1835.6 | 1838.1 | | 1838.1 | 0.07 | 188.1 | 20 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| FE | | ar | | 9 | 9 | | 9 | | 1 | |
| | | | | | | | | | | |
| YIRGACHEFE | 240 | 5year | 5 | 1836.78 | 1837.98 | | 1837.98 | 0.06 | 83.82 | 20 |
| YIRGACHEFE | 240 | 10year | 8 | 1836.78 | 1838.08 | | 1838.08 | 0.09 | 91.81 | 20 |
| YIRGACHEFE | 240 | 50year | 13 | 1836.78 | 1838.19 | | 1838.19 | 0.13 | 100.7 | 20 |
| | | | | | | | | | | |
| YIRGACHEFE | 200 | 5year | 5 | 1837.75 | 1837.91 | | 1837.98 | 0.52 | 4.77 | 24.15 |
| YIRGACHEFE | 200 | 10year | 8 | 1837.75 | 1837.99 | 1837.94 | 1838.07 | 0.58 | 6.92 | 34.05 |
| YIRGACHEFE | 200 | 50year | 13 | 1837.75 | 1838.09 | 1838.06 | 1838.18 | 0.67 | 11.14 | 50.94 |
| | | | | | | | | | | |
| YIRGACHEFE | 160 | 5year | 5 | 1837.56 | 1837.72 | | 1837.79 | 0.51 | 4.84 | 24.62 |
| YIRGACHEFE | 160 | 10year | 8 | 1837.56 | 1837.8 | | 1837.88 | 0.67 | 6.86 | 29.34 |
| YIRGACHEFE | 160 | 50year | 13 | 1837.56 | 1837.89 | | 1838 | 0.83 | 9.9 | 35.25 |
| | | | | | | | | | | |
| YIRGACHEFE | 120 | 5year | 5 | 1837.36 | 1837.51 | 1837.48 | 1837.58 | 0.54 | 4.52 | 23.7 |
| YIRGACHEFE | 120 | 10year | 8 | 1837.36 | 1837.59 | 1837.56 | 1837.68 | 0.69 | 6.5 | 28.42 |
| YIRGACHEFE | 120 | 50year | 13 | 1837.36 | 1837.69 | 1837.66 | 1837.8 | 0.86 | 9.53 | 34.4 |
| | | | | | | | | | | |
| YIRGACHEFE | 80 | 5year | 5 | 1837.16 | 1837.35 | 1837.29 | 1837.4 | 0.5 | 5.33 | 25.87 |
| YIRGACHEFE | 80 | 10year | 8 | 1837.16 | 1837.42 | 1837.36 | 1837.49 | 0.64 | 7.43 | 30.51 |
| YIRGACHEFE | 80 | 50year | 13 | 1837.16 | 1837.52 | 1837.46 | 1837.61 | 0.8 | 10.59 | 36.4 |
| | | | | | | | | | | |
| YIRGACHEFE | 40 | 5year | 5 | 1836.96 | 1837.09 | 1837.09 | 1837.18 | 0.59 | 3.9 | 22.15 |
| YIRGACHEFE | 40 | 10year | 8 | 1836.96 | 1837.17 | 1837.17 | 1837.28 | 0.76 | 5.76 | 26.89 |
| YIRGACHEFE | 40 | 50year | 13 | 1836.96 | 1837.26 | 1837.26 | 1837.4 | 0.94 | 8.62 | 32.84 |

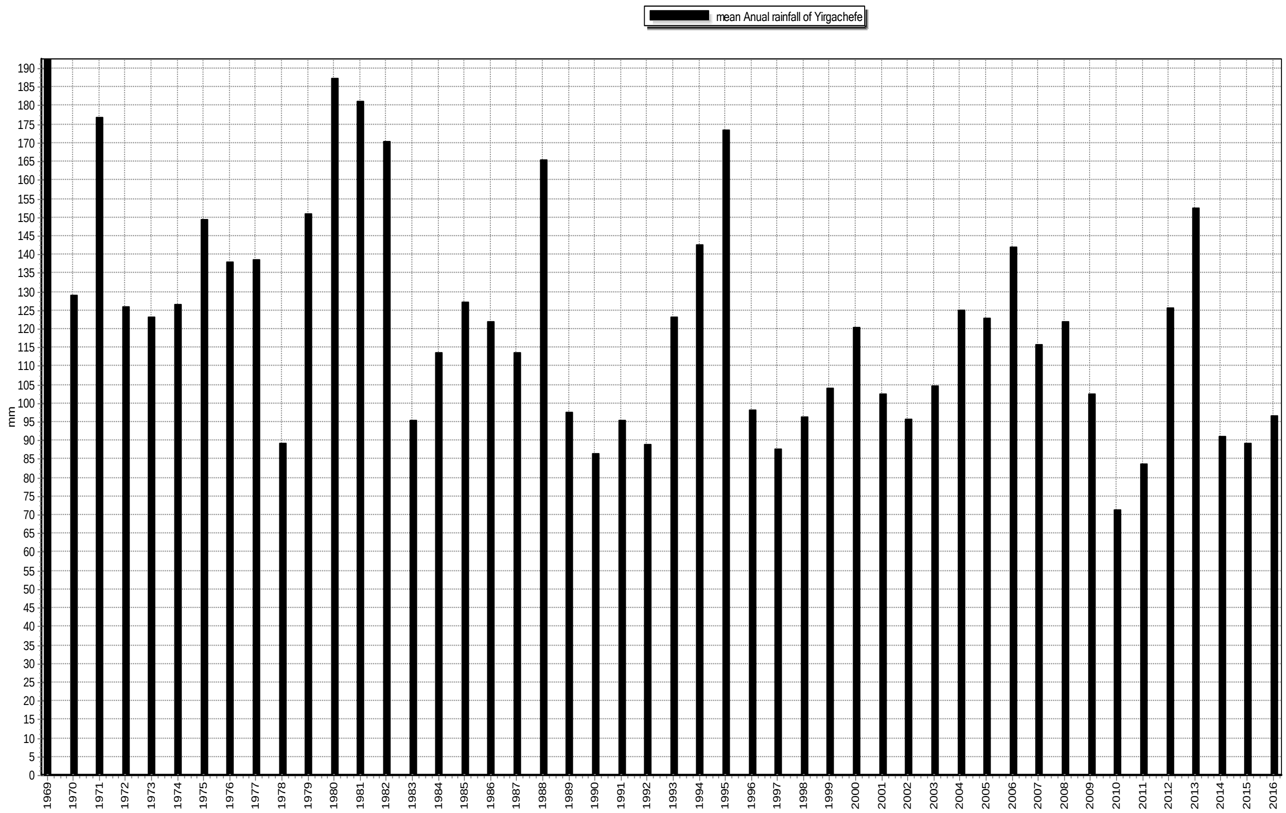



**Figure 25 mean annual rainfall of *yirgachefe* from 1969 - 2016**